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THE TECHNOLOGY QUARTERLY

AND PROCEEDINGS OF THE SOCIETY OF ARTS

VOLUME XX

BOSTON
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
1907

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THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY held its first meeting on April 8, 1862. By the act of incorporation, which was accepted at this meeting, the SOCIETY OF ARTS was created as a part of the Institute coördinate with the School of Industrial Science.

The objects of the Society are to awaken and maintain an active interest in the sciences and their practical applications, and to aid generally in their advancement in connection with the arts, agriculture, manufactures, and commerce. Regular meetings are held semi-monthly from October to May.

The Society discontinued the publication of the *Abstracts of Proceedings* in 1891, and since then has published its proceedings and the principal papers read at its meetings in the *Technology Quarterly*. The present volume contains the proceedings from October, 1906, to May, 1907, inclusive.

The *Quarterly* contains, also, the results of scientific investigations carried on at the Institute, and other papers of interest to its graduates and friends, and also a list of the publications of officers of the Institute, together with abstracts when possible.

Neither the Massachusetts Institute of Technology nor the SOCIETY OF ARTS assumes any responsibility for the opinions or statements in the papers.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Society of Arts

OFFICERS

1907-1908

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Secretary of the Society of Arts

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Editor of the Technology Quarterly

ROBERT P. BIGELOW

BY-LAWS.

Objects of the Society.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement and development in connection with arts, agriculture, manufactures, and commerce.

The Society invites all who have any valuable knowledge of this kind, which they are willing to contribute, to attend its meetings and become members. Persons having valuable inventions or discoveries which they wish to explain will find a suitable occasion in the Society meetings, subject to regulations hereafter provided; and while the Society will never indorse, by vote or diploma or other official recognition, any invention, discovery, theory, or machine, it will give every facility to those who wish to discuss the principles and intentions of their own machines or inventions, and will endeavor at its meetings, or through properly constituted committees, to show how far any communications made to it are likely to prove of real service to the community.

Section I. — Administration.

The immediate management and control of the affairs of the Society of Arts shall be exercised by an Executive Committee, consisting of the President of the Institute and the Secretary of the Society (who shall be members *ex officiis*), and five other members, who shall be elected by the Society of Arts at each annual meeting, to continue in office until other persons have been chosen in their place.

Sect. II. — Duties of the Executive Committee.

The Executive Committee shall elect its chairman, prescribe his duties, and, with the concurrence of the Treasurer of the Institute, fix his compensation when the interests of the Society require that

he should be paid for his services; they may invite any person to preside at any ordinary meeting who is well versed in the subjects to be discussed; they shall appoint the days and times of meeting, when not fixed by the Society, and determine the subjects to be considered at the meetings and the mode of conducting the discussions; they may, with the concurrence of the President of the Institute, make such arrangements for reporting and publishing the proceedings of the Society as they may deem best suited to advance its interests; they may receive moneys in behalf of the Society in aid of its objects, by subscription, donation, or bequest; they shall make a report of their doings to the Society at its annual meeting and such other times as a report may be called for by a majority of members present at any meeting; they shall also make a report of their doings to the President of the Institute prior to the annual meeting, and at such other times as the Corporation may require it. Three members shall constitute a quorum for the transaction of business.

Sect. III. — Duties of the President and Secretary.

1. It shall be the duty of the President of the Institute to preside at the annual and the special meetings of the Society, and also at its ordinary meetings when the Executive Committee does not invite a special chairman to preside.

2. It shall be the duty of the Secretary of the Society to give notice of and attend all meetings of the Society and of the Executive Committee; to keep a record of the business and orders of each meeting, and read the same at the next meeting; to keep a list of the members of the Society, and notify them of their election and of their appointment on committees; and generally to devote his best efforts, under the direction of the Executive Committee, to forwarding the business and advancing the interests of the Society. He shall also record the names of the Executive Committee attending each meeting.

Sect. IV. — Funds of the Society.

All the fees and assessments of members, and all moneys received by subscription, donation, or otherwise, in aid of the Society, shall be paid into the treasury of the Corporation, to be held and used for the objects of the Society under the direction of the Executive Commit-

tee, and shall be subject to the order of its Chairman, countersigned by the President of the Corporation.

Sect. V. — Meetings of the Society.

1. The annual meeting of the Society shall be held at the Institute on the second Thursday in May. The ordinary meetings shall be held semi-monthly, or whenever deemed expedient by the Society or by the Executive Committee, excepting in the months of June, July, August, and September.

2. If from any cause the annual meeting shall not have been duly notified or held as above required, the same shall be notified and held at such time as the Executive Committee may direct.

3. A special meeting of the Society may at any time be called by the Secretary on a written request of ten members. Twelve members of the Society shall constitute a quorum for the transaction of business.

Sect. VI. — Members and Their Election.

1. Members of the Society of Arts shall be of three kinds — Associate, Corresponding, and Honorary Members.

2. Candidates for Associate Membership shall be recommended by not less than two members, whose signatures shall be affixed to a written or printed form to that effect. Each nomination shall be referred to the Executive Committee, and when reported favorably upon by them, and read by the Secretary, may be acted upon at the same meeting; the election shall be conducted by ballot, and affirmative votes to the number of three-fourths of the votes cast shall be necessary for an election.

3. Corresponding and Honorary Members may be elected in the same way, on nomination by the Executive Committee.

4. Associate Members shall pay an admission fee of three dollars before being entitled to the privileges of membership, and an annual assessment of three dollars on the first of October of each year, this sum to include subscription to the *Technology Quarterly and Proceedings of the Society of Arts.*

An Associate Member who shall have paid at any one time the sum of fifty dollars, or annual assessments for twenty years, shall become a member for life, and be thereafter exempted from annual assessments.

A member neglecting to pay his annual assessment for six months after being notified that the same is due shall be regarded as having withdrawn his membership, unless otherwise decided by the Executive Committee, which shall be authorized, for cause shown, to remit the assessments for any one year; and which shall moreover be empowered to exempt particular members from assessments whenever their claims and the interests of the Society make it proper to do so.

Sect. VII. — Election of the Executive Committee and of the Secretary.

1. At an ordinary meeting of the Society, preceding the annual meeting, a nominating committee of *five* shall be chosen, whose duty it shall be to nominate candidates for the Executive Committee, to post a list of the names selected in the office of the Secretary, and to furnish printed copies thereof to the members at or before the time of election.

2. At a meeting at which an election is to take place the presiding officer shall appoint a committee to collect and count the votes and report the names and the number of votes for each candidate, whereupon he shall announce the same to the meeting.

3. A majority of the votes cast shall be necessary to an election.

4. In the first organization under these By-Laws, the Executive Committee may be elected at an ordinary or special meeting.

5. Vacancies in the committee occurring during the year may be filled by the Society at an ordinary meeting.

6. The Secretary shall be elected by the Society, on nomination by the Executive Committee, at each annual meeting of the Society, or, in case of a vacancy during the session, at such other time as the Executive Committee may appoint; and he shall be reëligible in the same way at the pleasure of the Society.

7. The compensation of the Secretary shall be fixed from year to year by the Executive Committee with the concurrence of the Treasurer of the Institute.

Sect. VIII. — Committees of Arts.

1. The Members of the Society of Arts may be enrolled in divisions, under the following heads, according to the taste or preference of

the individual; each division to constitute a committee upon the subjects to which it appertains:

(1) On Mineral Materials, Mining, and the Manufacture of Iron, Copper, and other Metals.

(2) On Organic Materials — their culture and preparation.

(3) On Tools and Implements.

(4) On Machinery and Motive Powers.

(5) On Textile Manufactures.

(6) On Manufactures of Wood, Leather, Paper, India Rubber, and Gutta Percha.

(7) On Pottery, Glass, Jewelry, and works in the Precious Metals.

(8) On Chemical Products and Processes.

(9) On Household Economy; including Warming, Illumination, Water-Supply, Drainage, Ventilation, and the Preparation and Preservation of Food.

(10) On Engineering, Architecture, and Ship-building.

(11) On Commerce, Marine Navigation, and Inland Transportation.

(12) On Agriculture and Rural Affairs.

(13) On the Graphic and Fine Arts.

(14) On Ordnance, Firearms, and Military Equipments.

(15) On Physical Apparatus.

2. Any member may belong to more than one of the above-named Committees of Arts, but shall not at the same time be eligible as chairman in more than one.

3. It shall be competent for each Committee of Arts, of ten or more members entitled to vote, to organize; to elect annually in October, or whenever a vacancy shall occur, a chairman; to appoint its own meetings; and to frame its own By-Laws, provided the same do not conflict with the regulations of the Society of Arts.

Sect. IX. — Amendment and Repeal.

1. These By-Laws may be amended or repealed, or other provisions added, by a vote of three-fourths of the members present at any regular meeting of the Society; provided that such changes shall have been recommended and approved in accordance with the By-Laws of the Corporation (see extract from By-Laws of Corporation as

printed below) and presented in writing at a preceding meeting of the Society.

2. These By-Laws shall take effect immediately after their approval by the Corporation and adoption by the Society, and all previous By-Laws are hereby repealed.

As amended December 9, 1897.

Extract from the By-Laws of the Corporation.

Sect. VI. — There shall be a Committee on the Society of Arts consisting of five members, appointed at the annual meeting of the Corporation, to hold office for one year, who shall have the general charge and supervision of the organization and proceedings of the Society, subject to the approval of the Corporation. It shall be their duty, in connection with a committee chosen by the Society, to frame By-Laws for the government of the Society, which shall take effect when adopted by the Society and approved by the Corporation.

Revised February 1, 1894.

LIST OF MEMBERS

DECEMBER, 1907

Members are requested to inform the Secretary of any change of address

THE CORPORATION

Life Members

Blake, Francis . . . . . Auburndale, Mass.
* Carson, Howard A. . . . . 15 Beacon Street, Boston, Mass.
Choate, Charles F. . . . . 50 State Street, Boston, Mass.
Crane, W. Murray . . . . . Dalton, Mass.
Draper, Eben S. . . . . Hopedale, Mass.
** Endicott, William . . . . . 32 Beacon Street, Boston, Mass.
Fairchild, Charles . . . . . 29 Wall Street, New York, N. Y.
Felton, Samuel M. . . . Railway Exchange Building, Chicago, Ill.
Fish, Frederick P. . . . . 84 State Street, Boston, Mass.
* FitzGerald, Desmond . 408 Washington Street, Brookline, Mass.
* Freeman, John R. . . . 815 Banigan Building, Providence, R. I.
* Hart, Francis R. . . . . Milton, Mass.
Higginson, Francis L. . . . . 274 Beacon Street, Boston, Mass.
Hubbard, Charles W. . . . . 133 Essex Street, Boston, Mass.
Jackson, Charles C. . . . . 19 Congress Street, Boston, Mass.
Lee, Elliot Cabot . . . . . Brookline, Mass.
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* Lowell, A. Lawrence . . 171 Marlborough Street, Boston, Mass.
* Lowell, Percival . . . . . 53 State Street, Boston, Mass.
Mills, Hiram F. . . . . 266 Andover Street, Lowell, Mass.
* Munroe, James P. . . . . 79 Summer Street, Boston, Mass.
Paine, Charles J. . . . . 613 Sears Building, Boston, Mass.
Peabody, Robert S. . . . . 22 The Fenway, Boston, Mass.
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* Rotch, A. Lawrence . 1124 Board of Trade Building, Boston, Mass.
Sewall, J. B. . . . . Brandon Hall, Brookline, Mass.

Stearns, James P. . . . . National Shawmut Bank, Boston, Mass.
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* Stone, Charles A. . . . . 84 State Street, Boston, Mass.
Thayer, Nathaniel . . . . 50 State Street, Room 82, Boston, Mass.
* Thomson, Elihu . . . . . 42 Centre Street, West Lynn, Mass.
* Tolman, James P. . . . . 88 Broad Street, Boston, Mass.
Tuttle, Lucius . . . . . 3 North Station, Boston, Mass.
Whitney, David R. . . . . 85 Devonshire Street, Boston, Mass.
* Wigglesworth, George . . . . . 53 State Street, Boston, Mass.
* Williams, Francis H. . . . . 505 Beacon Street, Boston, Mass.

Term Members

Term expires March, 1909

Newell, Frederick H. . U. S. Geological Survey, Washington, D. C.
Soule, Richard H. . . . . 1571 Beacon Street, Brookline, Mass.
Stevens, Eben S. . . . . Quinebaug, Conn.

Term expires March, 1910

Copeland, Frederick K. 1506 Railway Exchange Building, Chicago, Ill.
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48 Boylston Street, Boston, Mass.

Term expires March, 1911

Du Pont, T. Coleman, E. I. du Pont de Nemours Powder Co.,
Wilmington, Del.
* Main, Charles T. . . . . 1110 Exchange Building, Boston, Mass.
Wood, Frederick W. . . Maryland Steel Co., Sparrows Point, Md.

Term expires March, 1912

Hale, George E. . . . . Solar Observatory Office, Pasadena, Cal.
Kittredge, George W. . . Grand Central Station, New York, N. Y.
* Stantial, Frank G. . . . Cochrane Chemical Co., Everett, Mass.

On the part of the Commonwealth

His Excellency the GOVERNOR
The Honorable the CHIEF JUSTICE OF THE SUPREME COURT
The Honorable the SECRETARY OF THE BOARD OF EDUCATION

* Associate Member, Society of Arts
** Life Member, Society of Arts

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VISITS TO EUROPEAN NAVY YARDS AND SHIPYARDS DURING THE SUMMER OF 1906

By CECIL H. PEABODY

THE policy of all leading maritime nations is to build the major part of their warships in their private shipyards and to equip and repair ships in the governmental navy yards; at the same time all important navy yards have provision for building ships, and some construction is usually in progress. This policy encourages private enterprise and develops the capacity for shipbuilding, both governmental and private, so that all resources may be available in time of need. The first impression that a visitor gets of an important navy yard is consequently made by the provision for equipping and repairing ships, consisting of tidal or closed basins, dry docks, and cranes or derricks, together with a vast assemblage of shops and storehouses for making and storing the numberless things that are required for equipping a warship. As governments are apt to be even more conservative than private firms, it is likely that the buildings and appliances will be found to be old and sometimes inconvenient, or old and new may be found in incongruous juxtaposition. These considerations, together with incommunicativeness of European governmental officials, will explain why there is less to report from navy yards than from private yards; though of private yards it may be said that some were generous in giving information and others were reserved, depending on personal inclination.

Six navy yards in all were visited and thirteen private yards. One navy yard was selected in England, in France, and in Germany, and three were visited in Italy, the arrangement being determined in part by the limitations that appeared proper in arranging an extended trip covering a considerable territory and with other objects in view of at least equal importance, and in part by the fact that important English and French navy yards had been previously visited. Two of the Italian yards were of special interest, one for an experimental model station and the other for the importance of its new construction.

Portsmouth is the principal naval station of Great Britain, and is also the location of the largest and most important dockyard. Some idea of its extent can be learned from the fact that there are eighteen dry docks, not counting certain passages from the tidal basin to closed basins which can be used as docks if necessary. A large amount of the work of equipment and repair of ships is done while lying alongside of wharfs in closed basins, this giving advantages from the fact that the water level remains fixed and the ships do not rise and fall with the tide. The entrance to such closed basins is through locks with gates at each end, and depends on the stage of the tide in so far as that controls the convenient entrance to a lock from the tidal basin. The number of slips available for building has been reduced recently to provide for the increasing demands for equipment and repair; this is in conformity with the policy of giving the major part of new construction to private yards. At the same time the slips retained have been lengthened as demanded by the increase of size of warships. On one of the slips was built the *Dreadnought,* which is remarkable for its speed and power and for its rapidity of construction. The keel was laid in October of 1905, and the ship was launched in February, four months later; now the ship has been placed in commission, and has passed through the power and speed and gunnery trials within a year from the date of launching. This ship was seen in dock, but information was given that even British naval officers could not go aboard without special permission.

Alongside of the slip where this ship was built was a ship tool house, into which material was brought by rail as required. After being machined, this material was passed through the open side of the shop to the slip and hoisted into place by wooden derricks. This method of using a row of wooden derricks on each side of the building slip is common in Great Britain and has some advantages, especially when hoisting is done by electric winches.

A large, new machine shop has just been completed with most modern machinery and appliances on land that has recently been added to the yard.

The principal Mediterranean naval station belonging to France is at Toulon, and there is found one of her oldest and most important navy yards. There was no building going on at this yard when visited, excepting submarine boats, and they were at a detached yard across the harbor and were entirely closed to visitors. As there is practically no tide in the Mediterranean Sea, there is no occasion for closed basins. There were formerly in this yard a number of imposing ship houses built of stone in the classic style, but they have been destroyed by fire, and only the scorched side walls remain. The location of the slips has been largely converted to the purposes of equipment, as that feature has been more emphasized. The half ruinous and temporary appearance of much in this yard had an unfortunate effect, and led to the consideration of the economics forced on the navy by the enormous burden of the French military establishment.

The undeveloped condition of shipbuilding in Italy, except at one or two private yards, has led to the construction of an unusually large part of the warship at the navy yards. Of these the yard at Castellamare appears to be in the best condition for building. This yard is near Naples, and for administrative purposes is considered to be a part of the arsenal, or navy yard, at Naples, which latter is old, small, and poorly arranged, and is used only for small repairs and for fitting out the ships that are built at Castellamare. The yard at Castellamare appears to be rather contracted, and the arrangements of new construction appear to be unduly affected by that condition; otherwise the yard is, or will soon be, in first-class condition for building a small number of ships. There are two masonry slips of solid construction; on one of these *St. George* is building, and arrangements were under way at the time of my visit to build a very powerful ship with steam turbines. A large, new shop for ship tools, with a "saw-tooth" roof, has just been completed, and is partly supplied with powerful modern tools; some are English tools and some are of local design. The equipment of this shop was in progress, and when completed will give every facility in that direction. There are a number of old shops, with small tools and forges for making ship fittings.

The materials for shipbuilding are brought to the yard by rail, but inside the yard are transported entirely on two-wheeled handcarts and hoisted by derricks at the slips.

In this yard there is a complete plant of English machinery for making rope, with breaking, combing, drawing, and ring-spinning machinery. The material is hemp raised on the campania, and is considered superior to manila hemp.

Another Italian yard at which building is in progress is at Spezia, which is the principal naval station. This yard, which is very large and in general very well arranged, is employed mainly on equipment and repairs, and the new construction is said to be subject to delay on account of the pressure for repairs. There are two slips for large ships and two for smaller ships. The bending slab and a shipsmith shop are alongside the outermost slip; the other shops for ship tools, etc., are placed across the inner ends of the slips, so that they are convenient for all of them. Material is transported in the yard by handcarts only, but is hoisted up to the slips by electric winches, the derricks being constructed from discarded military masts taken from naval vessels. Over the ship was spread a canvas awning, to protect it and the workmen from the sun, which at the end of May was already very oppressive in the yard. It may be noted, in passing, that Spezia has the reputation of being favorably located, so that the temperature is moderated by sea breezes. The ships built at Spezia and also those built at Castellamare are supplied with engines built by private firms, such as Guppy or Patterson, at Naples, or Ansaldo-Armstrong, at Sestri Ponenti.

The navy yard at Venice is old and small, but is now in process of reconstruction; and when remodeled will be an effective yard for its size, and will be important on account of its location, though it is probable that it cannot be readily enlarged on account of local conditions. The only important work in progress, aside from the reconstruction of the yard, is the building of submarine boats, which, as usual, was going on in closed shops not accessible to strangers.

The last navy yard to be visited was at Kiel, the principal German naval station; and, as was to be expected, this proved to be a large, well-arranged yard with the most modern appliances. It has recently been enlarged at the expense of the Germania shipyard, which in consequence has been forced to acquire other land at some disadvantage. There are now four old and comparatively small docks at this yard, and two new docks that can accommodate the largest ships that have been planned.

This yard is, in a manner, the home station for a large number of vessels of all classes, including many torpedo boats. Each vessel that is so related to the yard has a section in a storehouse which is specially

assigned to it. In that section will be found all the spare parts and other material that the ship is likely to require on short notice, ready for immediate delivery. The officer who acted as guide pointed out certain sections belonging to ships in active service which were sparsely occupied by such things as a ship might need promptly, but which could not conveniently be carried aboard; other sections belonging to ships laid up at the yard were nearly full of material that it was considered best to have in such a storehouse, all arranged in systematic order, so as to be open to inspection and immediately available. It may be of interest to call to mind that after the proclamation of the German empire the reorganization of the navy was at first entrusted to a cavalry general, who, however, never had a command at sea. This arrangement of spare parts and supplies is only one of many indications that the German navy is at all times kept in condition for immediate service.

In planning a tour of inspection of private shipyards, it was considered best to select the best examples in the various countries visited, taking account of any special conditions, such as continued experience over a term of years, or recent construction in favorable location, or the specialization on a certain class of work. Some yards that have a wide reputation were omitted, either because they would require an undue extension of a trip already sufficiently extended, or because they had been previously visited, in some cases more than once. The order followed will be that of the itinerary of the trip, which will call attention to the Continental yards that had not been previously seen.

The first private shipyard visited was at La Seyne, across the bay from Toulon, an old established yard that has apparently developed in an individual manner, and consequently presented many points of interest. The yard has plenty of room, and has especially a long water front without being unduly limited in width. About the middle of the length of the yard is a large, wet basin for finishing and fitting out ships after they are launched. In front of this basin are the administration offices and drawing offices, which are the centre of administration and supervision. To the left of the basin are three slips for small ships, and at the right are three slips for large work, all with masonry foundations. These at once give a measure of the importance of the yard. To the left and right beyond the slips are shops that come down to the water front, so that work may be taken from them on floating cranes when that method of transportation is convenient. There are also two marine railways, one at the left for small craft, and one at the right for large ships.

In much the same manner as the slips and shops along the water front are related to the wet basin at the middle, the shops for the various industries required for building a ship are distributed along the landward boundary wall to the right and left of the offices. To the left are a series of shops, in one continuous building, for making rivets, for copper work, and for electric fittings. To the right, and therefore across the front of the large building slips, are two ship tool shops, with bending, flanging, and planing machines, including an armor-planing machine. In these shops are shears, punches, and drilling machines, but in addition shearing and punching machines are scattered through the yard, especially between the slips, without any protection from the weather. This arrangement is found more or less all over the Continent, even in Germany, and to some extent in Great Britain. It is to be remembered that in none of these regions where shipbuilding is found do they have the semi-arctic winter of the North Atlantic seaboard. The use of electric transmission of power lends itself to such a scattering of tools, and is increasingly used both at La Seyne and in other yards where the tools are found between the slips. The carpenter shop and mold loft are found to the right of the large ship tool shop. One feature worthy of note is the large size of plating models, some of which are 20 feet long.

All material comes to the yard on wagons drawn by horses, entering at the extreme left and with an open avenue running the length of the yard. There is no other means of transportation than by horses or by men, except as heavy materials and structures are moved by floating cranes, of which there are four in all, one lifting 80 tons, one 50 tons, and two 20 tons each. This extensive use of floating cranes is one of the advantages of the tideless sea on which the yard is located, for as there are no appreciable changes of sea level there are no tidal currents, and as the water front is well protected from the open sea cranes with their loads are easily moved from place to place. The material when brought to the building slips is hoisted by electric winches. A feature of this yard, which showed many evidences of age, was the large and increasing use of electric transmission of power. The material for shipbuilding was stored at the two ends of the yard beyond or in front of the shops at the water front, the principal store being near the entrance, where there was a traveling crane to assist in unloading and loading plates onto wagons and handcarts, but it was worked by hand.

There are two features in this yard that are worthy of special mention, namely, wet ends for building slips and the large marine railway. The

marine railway is notable in consequence of its size and power, and in that it appears to be used instead of a dry dock. The ship to be hauled up is placed on a cradle on sliding ways lubricated as for launching. At the inshore end of the sliding ways is a heavy crossbar, to which are attached two hauling rods about 8 inches in diameter. The motive power is furnished by two hydraulic rams about 15¾ inches in diameter, with a stroke of about 13 feet; and as the hauling rods are made in sections having the same length, the ship may be hauled up intermittently 13 feet at a time, the rams being run back while a section of the hauling rods is being removed. The cradle, when not in use, is drawn up on the railway by electric winches.

Wet ends for building slips are found in shipyards both on the Mediterranean and the Baltic Seas, both being free from tides. The device has certainly been long in use at La Seyne, if it did not originate there. It appears to be employed to give the same advantage at launching that is had on the open sea by choosing an extra high tide for launching, at which time the water extends a considerable distance up the slip. To prepare a wet end, the earth is excavated to the slope of the building ways, side walls of masonry are built, and a gate is provided to exclude the water. The water is pumped out as from a small dry dock, and sluices are provided to flood the space when desired. The gate can be lifted by a floating crane, and thus be put in place or removed when required. Small craft can be docked or repaired in such a wet end when the slip is not otherwise occupied.

The most important Italian shipyard belonging to the Ansaldo-Armstrong Company is located at Sestri Ponenti, near Genoa. It is noted for its construction of ships of large size and power for the Italian and other navies. The *Christobal Colon* was built at this yard and purchased by the Spanish government, just before the difficulties that led to the battle at Santiago. This shipyard is compact and well arranged, with slips for building five or six ships. At the time of my visit there was no work in hand except a number of torpedo boat destroyers on temporary blocking. There were excellent ship tool and forge shops in a central location, with powerful modern tools. Here, as at La Seyne, shears and punches were set in the open between the slips. A branch from the railroad enters the yard at one end and passes under some of the building slips. One of the slips is to be lengthened over the main line of the railway which skirts the inshore side of the yard. The slips, which are built of masonry, stop 40 or 50 feet short of the water edge, which is

the open sea at the Gulf of Genoa. The ships are launched over the beach on a fore-slip that is kept in readiness and is put in place rapidly just before the day chosen for launching, because the beach shifts quickly and to a considerable extent. Material is transported on handcarts within the yard, and is hoisted by hydraulic lifts between the slips. Electric winches are to be substituted for these lifts.

A remarkable sociological question was raised by the superintendent, who said that the trades unions desired to have the working day limited to eight hours, while the workmen, who were paid by the hour, insisted on working twelve hours, which he thought was undesirable from the company's point of view, as men cannot work effectively such long hours.

The Vulcan shipyard, at Stettin, is an old establishment that has taken a leading position in the modern development of the German shipbuilding. It has grown with the growth of shipbuilding until it has outgrown its location, and the yard is consequently cramped and subject to some inconvenience of arrangement. At the time of my visit a plan was in hand for a new shipyard, with a logical arrangement and the most modern appliances, at Hamburg, but it was not then accepted. The establishment is divided by a public street, the shipyard proper being on the water front, and the foundry, machine shop, boiler shop, etc., being on the opposite side of the street. This latter part of the establishment included a locomotive shop, and is capable of doing work in excess of the requirements of the shipyard.

The yard will be described first by aid of the accompanying plan (Fig. 1). It has four slips for large ships, all under ship houses with traveling cranes. Each slip has two cranes, one somewhat longer than half the breadth of the slip, so that its trolley can deliver material directly on the keel; the other crane is of course shorter, and serves the other side of the slip. There are three shorter slips that are not under ship houses. All these slips have wet ends like those seen at La Seyne, the condition of the yard on a tideless sea being quite similar. Some of the wet ends were in use as dry docks for repairing small craft. This yard further resembled the Mediterranean yards in that shears and punches were distributed around the yard near the slips, but they were in general covered with small galvanized iron shelters. This distribution of tools and the large number of small sheds and the haphazard extension of shops to suit the growth of work give to the whole establishment an appearance of lack of system which a more careful consideration shows to be mainly superficial. Thus the plate storage is placed beyond the

slips near the water front, in consequence of the narrowness of the yard, and the joiner shop, sawmill, and timber store are beyond the plate storage, which arrangement was made deliberately, so that a fire in the

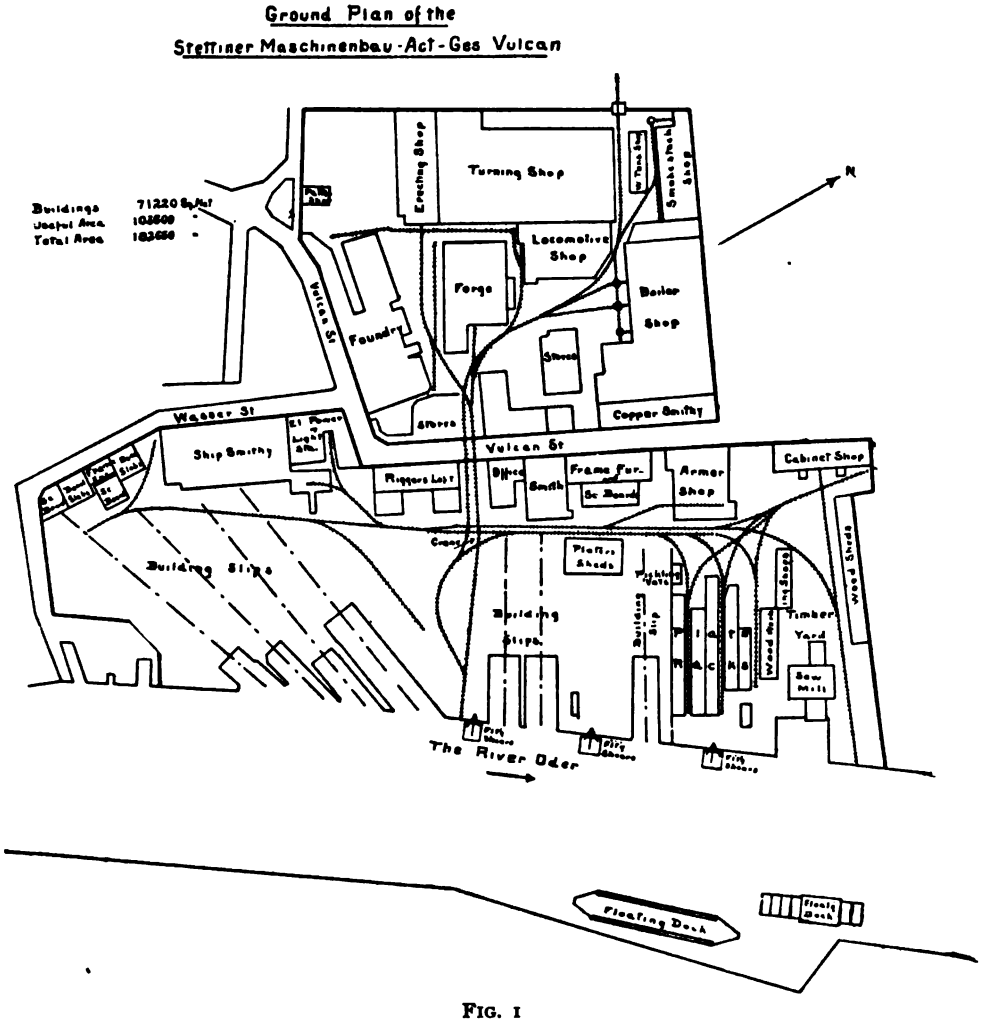


FIG. 1

wood shops would not be communicated to the building slips. The entrance to the yard from the street is at the middle of the length. To the left on entering, the row of buildings on the street are an office, a shipsmith shop, a heating furnace, and two bending slabs and accompanying scrive boards, and then an armor plate shop; beyond, in the

corner of the yard, is the cabinetmaker's shop. To the right is first an assemblage of small buildings, then a shipsmith shop with galvanizing tanks, and in the right-hand corner of the yard another heating furnace, with two bending slabs and scrive boards, which serve the larger building slips. In this corner of the yard the crowding is most evident. Throughout the yard is a very complete system of standard gauge rails that extends into the shops and foundry on the opposite side of the street, and which connects with the railway system. The equipment of the yard includes two floating docks (one capable of taking large ships), which lie on the further side of the Oder, and which must be moved to allow for launching large ships. There are also two catamaran floating cranes, one capable of lifting 150 tons, and the other 120 tons. The location of this yard on a tideless sea lends itself to the convenient use of floating cranes.

The depth in front of the launching slips has been dredged to 33 feet and the depth in the channel to the open sea is maintained at 24½ feet, and yet the company, as already said, has decided to establish a yard at Hamburg, where there is not such a restriction on draft.

The enclosure containing the machine shops, boiler shops, etc., on the further side of the street, has less than half the frontage of the shipyard, but has sufficient depth to compensate, and the shops, though closely assembled, do not give the same impression of crowding. At the entrance are the office building and a general storehouse. Taking a circuit of this yard towards the left, there is formed first a long building with traveling cranes, which is the iron and steel foundry; only small steel castings are made, but there is every appliance for making the large and intricate iron castings demanded by modern marine engines. On the floor of this shop, at the time of my visit, there were a number of molds for cylinders and other large castings in various stages of completion, offering an interesting exposition of this most difficult part of the molder's art. To the right of this shop, as seen on the plan, is the blacksmith shop, with power hammers of moderate power; all large forgings are made elsewhere. Beyond the smithy is a large machine shop, with its equipment of heavy machine tools and erecting floor. Adjacent to the shop for building marine engines is a shop where locomotives are built. At the right of the enclosure is a group of buildings, which are the boiler shop (for both marine and locomotive boilers), the coppersmith's shop, and a shop for building smokestacks and uptakes. As already mentioned, the yard system of rails is brought to or into all of these

shops, and it connects with the railway system at the northwest corner of the enclosure.

One peculiarity in the machine shop was a double-decked arrangement of traveling cranes, one set on a track above that for the other, so that either crane could traverse the whole length of the shop (when unloaded) without interfering with the other, and thus each could be made to serve any part of the shop, and both could carry loads at the same time nearly the entire length. A few minor details were noticed in the machine shop; for example, the eccentric strap, instead of having a straight cylindrical bearing surface on the eccentric, with lips to maintain alignment, had a double wedge-shaped bearing that dispensed with lips, as shown by the sketch (Fig. 2).

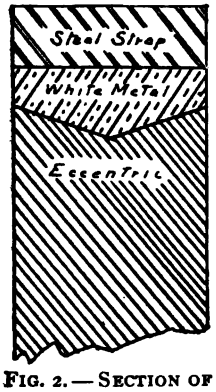


FIG. 2. — SECTION OF ECCENTRIC STRAP

Some double-ended marine boilers under construction had common combustion chambers for opposite furnaces, an arrangement which reduces the length and weight of the boiler, but which has been found to lead to troubles in service. Consequently it would appear that German engineers have not found such troubles insurmountable. A very ingenious swaged joint was seen for the corners of the shell plates of marine boilers, which is too technical for description in this report.

The management of this establishment was most liberal in giving information and every facility for seeing the yard and work in progress, and even showed a proposed plan for the new establishment at Hamburg.

The largest and most recent German shipyard is the Germanic Werft, at Kiel, which was laid out *de novo* in 1896 by Krupp, in connection with his extensive steel enterprises. It adjoins the navy yard at Kiel, and the government has taken land on the water front that formerly belonged to this yard, and that may account for the relatively narrow water front of the yard as now laid out. It is, however, possible that the width of the yard may be extended on the side remote from the navy yard, if that should appear necessary. As the land rises back from the water front, the foundry and boiler shop, as well as the pattern shop and the electric station, are on land that has been excavated to a considerable extent, and which shows high retaining walls on three sides. As the yard is now arranged, there is but little allowance for future growth. This may not be of importance, as the original plan is on a

very large scale, and the works are probably as large as can be run advantageously under a single management. The plan of the yard which accompanies this description (Fig. 3) shows that it is compactly and conveniently arranged to carry on a very large business. At the time of my visit there was relatively a small amount of work in hand, which condition always presents an unfortunate appearance. The construction of building slips, ship houses, machine shops, etc., is substantial, and they are equipped with the most recent machinery and means of handling material, such as fixed and traveling cranes. It is, however, a little remarkable that electric transmission of power is not carried to a further extent; for example, all the tools in the machine shop are driven by belts. In general, the impression is that the design of the yard is conservative, not to say commonplace. On the other hand, the administration offices are in a pretentious building in the Old German style of architecture.

The water front of the yard faces to the north and west, there being an obtuse angle of about 150° at about two-fifths of the length from the northern end. The building slips lie to the north of this bend, and face nearly due north. There is space for ten slips, of which seven are now completed, which vary in length progressively from 450 to 750 feet; the three projected slips are much longer, running up to a possible length of 1,000 feet. The first four shorter slips are covered with lofty ship houses with glass roofs, supported by the framework which carries the traveling cranes. These cranes, which convey material to the ships and support it in place during construction when that is advisable, are in pairs, each slip having two, one on each side of the keel blocks; heavy weights or material to be delivered directly over the keel can be carried by the pair acting in unison. Across the inner end of the slips is the ship tool house, and at right angles with this shop, under a continuous roof, are a series of shops, such as the ship's forge shop and the frame bending shop. The plate storage is in the angle between the shop just mentioned, and being triangular in form is conveniently served by a radial crane; one end of the frame of this crane rests on a pivot, and the other rolls on a circular arc. At a corner of the plate storage is the pickling tank, to remove mill scale from plates.

On the longer side of the water front, which runs a little east of north, is a continuous fitting wharf, served by four cranes with the capacities of 30 to 150 tons. Near the southern end is the machine shop for building and erecting engines. Adjacent to it and between it and

the ship tool house is an assemblage of small shops, such as the coppersmiths' shop, the joiner shop, and the locksmith shop. In this same space is a shop with several slips for building torpedo boats.

The machine shop is all one story high, arranged in four bays, of which one, where the engines are erected, has a greater height than the others. In front of the erecting bay is the 150-ton crane already men-

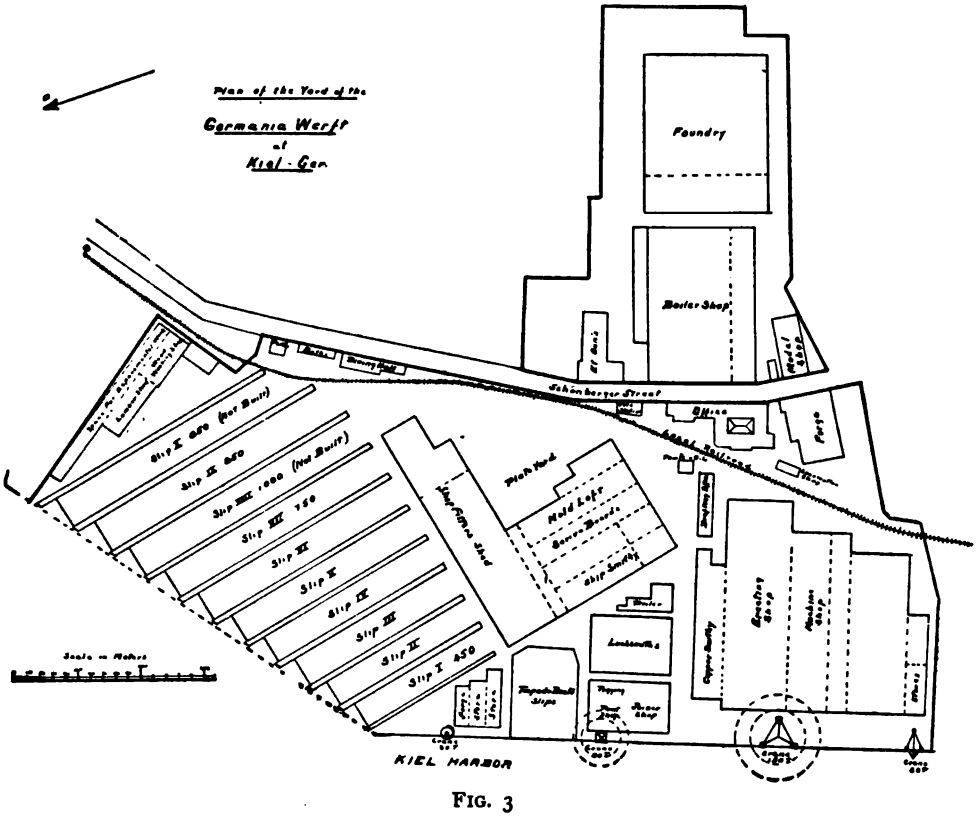


FIG. 3

tioned, which serves to place the engines on board the ships. A small power hammer shop lies behind the machine shop, next to the administration building. Large forgings come from the Krupp Steel Works at Essen.

As shown by the plan, this yard is bisected by an important public street, beyond which are placed the boiler shop and foundry, in land that has been excavated down to the yard level. The boiler shop fronts on this street directly opposite the office building. It is provided with the

usual machinery for building large marine boilers, both of the shell and the water tube types. The shell riveting machines are set in pits 8 feet deep, so that they get the head room necessary without requiring a tower over them. There are two furnaces in this shop for heating plates that are either bent to a small radius or are made into complicated forms.

Beyond the boiler shop is the steel and iron foundry, a very large shop for making the largest castings required for marine engines. It has several bays, each served by traveling cranes, and there are a number of post cranes among the columns that divide the bays. These latter are built up of angle bars and plates, and appear clumsy in design.

The pattern shop and the electric station are on the public street, on either side of the boiler shop.

Two evidences of the liberal views of the management are shown by the admirable provisions for bathing houses and eating houses for the employees, and by the large space assigned, near the north boundary of the yard, to the testing department.

The two most noted localities for shipbuilding in Great Britain are the northeast coast and the Clyde. Four of the leading yards which have individual characteristics were visited in each locality.

The first English yard to be visited was that of William Doxford and Sons, at Sunderland, which is especially interesting because they build only one special type of ship in large numbers, and consequently may be said to *manufacture* ships. This type of ship, which was suggested by the whale-back ships of the Great Lakes, has the topsides drawn sharply in above the water line, and the sides are then carried up vertically with a width about half the beam of the ship. They are all freight ships, with accommodations for only the officers and crew. A member of the firm who showed the yard gave the information that they could build ships at the rate of two a month, and that a ship could be launched in fifteen weeks if there were no delays. The engines and boilers are finished in anticipation of the launching of the vessel to which they belong, and are loaded on flat cars a day or two in advance. Immediately after the ship is launched these flat cars are run down to the finishing slip in proper order, and the material is placed aboard by a 50-ton crane. Two days are sufficient to get all the machinery installed and to get steam up. The joinery work, which is plain and small in total amount, is also ready, and the ship can soon be ready for sea. If a ship is launched in the morning, the ground is at once cleared and the keel for the next ship is immediately laid with material already prepared.

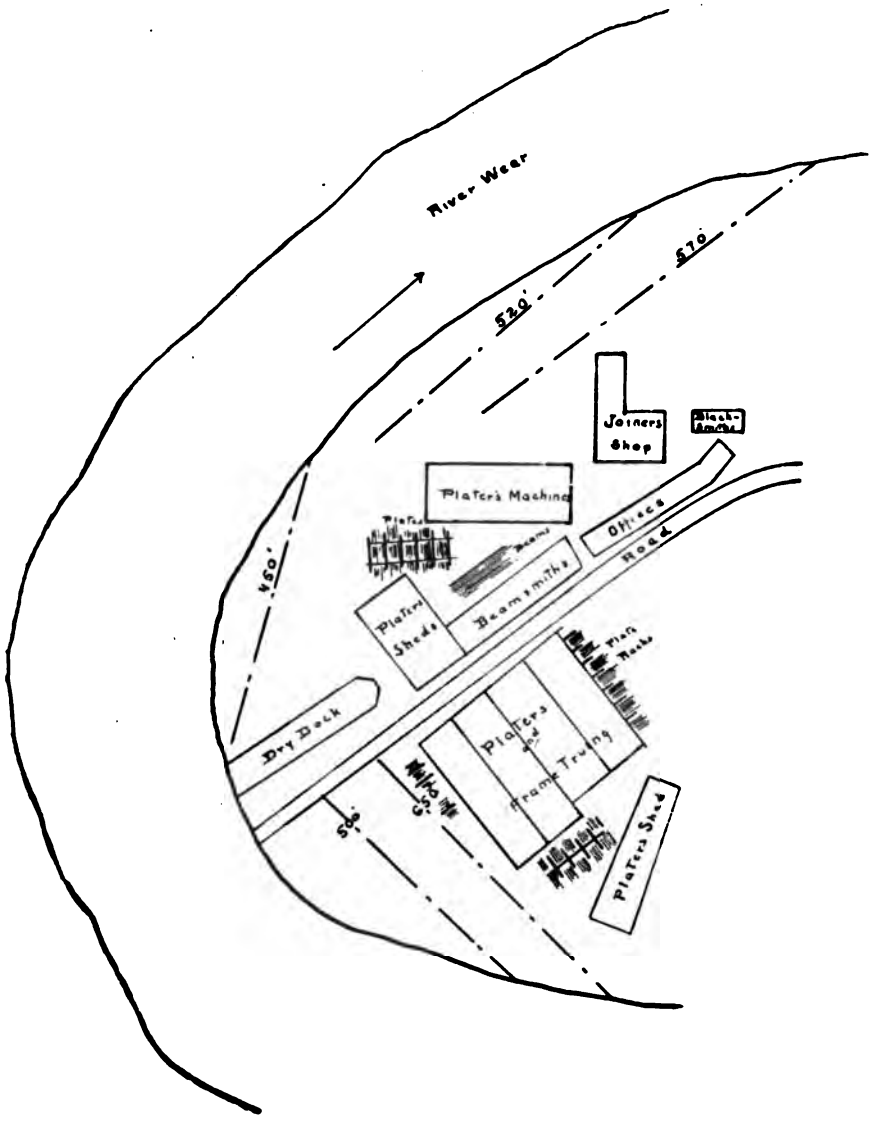
A large portion of the body of the ship is straight work with identical framing, a condition which lends itself to the method which originated on the Great Lakes, of laying out frames to a templet and assembling them and riveting them before they are sent to the slip. In consequence, the building can go on with great rapidity.

This yard, which lies along the Wear, has considerable water front, but is very narrow. When it was necessary to enlarge the yard, land down stream was secured; and as the land rose rapidly from the river, it was necessary to do much excavation to gain the space needed at the level of the yard. A line of rails runs on the edge of the bank above the yard, and the slope from the rails to the yard facilitates sliding material down to the level of the yard.

The fitting out wharf may be taken as the centre of the yard. It is a plain wharf barely long enough for one ship, so that where there are two ships fitting, as at the time of my visit, one must lie outside the other. The fitting crane is able to deliver boilers to the ship lying outside. The river, like most British streams, is narrow, and the building slips make a comparatively sharp angle with the margin of the river. There are three slips that point up stream and three that point down stream; the latter three, which are the newer, have overhead traveling cranes for handling material. It was said that the older slips were to be similarly provided when convenient. The advantage of such cranes was said to be rather in the saving of time than in direct reduction of expenses. It is probable that the conditions of manufacturng ships of one type are favorable for the introduction of mechanical devices, and such conditions are found in this yard and in the yards in our Great Lakes, where there is no question in the minds of those in control concerning the advantage of such devices. There is much difference of opinion concerning the economic advantage of elaborate mechanical systems of transportation in yards where the conditions are different. Over each of the slips which was provided with traveling cranes there were four longitudinal members in the roof or overhead structure, the whole length of the slip starting at the water's edge and running far enough beyond the inshore end to reach conveniently material brought to the head of the slip. On each of these longitudinal members there was a trolley driven by electricity, which carried a jib with a reach of somewhat more than one-eighth of the width of the slip measured to the row of posts supporting the overhead structure; thus all parts could be served by at least one of the trolleys. Heavy weights could be carried

by one, two, three, or all four trolleys, as might be convenient. Through the yard was a convenient system of rails at the usual gauge on railroads, so that material could be brought from outside or from any shop to the required place. There were also a number of locomotive cranes, found also in some other British yards; for example, at Armstrong's yard at Newcastle. The external appearance of one of these was not unlike a small locomotive, with a dome over the fire box, in which was a vertical cylinder looking upwards. The crosshead at the end of the piston rod slid in vertical guides, and was connected directly to the short end of a horizontal lever, or crane-arm, reaching beyond the front end of the locomotive; the fulcrum of this lever was supported by links from the frame of the locomotive, so as to give the required flexibility to the linkage. These cranes were said to be convenient and rapid in action and could be used to draw cars like ordinary locomotives. It may, however, be said that the same type had been tried in other yards and rejected in favor of the more ordinary locomotive crane with small vertical boiler and swinging jib.

Each group of slips has its own bending slab and ship tool house, an arrangement which is favored by the configuration of the yard, and which came naturally with the extension of the yard in a narrow space between the river and the railroad. Angles and other bars and beams are delivered from flat cars on the line of rails on the bank above the yard, and are slid down to the bending slabs; as there is little variety of such material the handling is simple. The plate yard is above the building slips, just below the same line of rails. The machine shop and boiler shop lie side by side and adjacent to the office building up stream, beyond the older building slips. They are supplied with the most recent and powerful machines, it being the policy of the company to replace any machines by a better one when that appears advisable, no matter how recent the condemned machine may be. In the process of supplying the machine shop with modern tools it was found necessary to import some tools from America before the British tool builders could be made to build the tools desired, but when the British equivalents were available they were preferred because they were stiffer. The machine shop is of the usual form, with a wide central bay served by traveling cranes, and with two side aisles over which there are galleries for small tools. The large tools on the floor were drawn well back into the side aisles, so that the main bay was available for material in hand. There has been much increase in the rate of machining engines and other parts in the



Sketch Plan of Yard of
Sir James Laing & Sons at
Deptford

Not to Scale

FIG. 4

last two years, which was made possible by the improvement in the steel used for cutting tools. At the time of my visit there were six engines of one pattern in process of erection, and as many more in course of construction.

Down stream from the yard of William Doxford and Sons, at Sunderland on the Wear, is the yard of Sir J. Laing and Sons, which is engaged in building high class passenger and freight ships, scarcely two of which are quite alike. The conditions of building ships in this yard are almost the converse of those in the yard just described, and the peculiar relation of the yard to the river into which the ships are launched emphasizes the difference. They have five slips in all, as shown on the accompanying sketch (Fig. 4), and they can build seven ships in a year, which, considering that many of the ships are much larger and that the fitting is likely to take more time than the building of ships of this class, is no less creditable than that of the yard just described.

As will be seen from the sketch, the yard lies in a bend of the river nearly a semicircle in extent. The building slips are distributed in what looks at first sight like an erratic manner, but which is demanded by the configuration of the water front, bearing in mind that the ships must be launched into a narrow stream. This arrangement of the slips throws the various shops into a group in the centre of the yard, which makes the transportation of material and the superintendence of work comparatively easy, even though there is no special method of handling material. It may be noted, also, that there are no engines or boiler shops, which further simplifies the conditions. A wagon road runs across the yard past the offices and shops down to the dry dock. There is one large shop for bending frames and for working plates, and three smaller shops for plating work, with plate stakes adjacent; and there is also a shop for smithing beams. These, with the blacksmith shop and the joiner shop, complete the outfit for this yard. At one of the slips they have a number of steel derricks built of angles and plates for hoisting materials to the ship, and through the open bases of these derricks they have a Temperly conveyor, consisting of a system of trolleys on an overhead rail drawn by a continuous wire rope. The other slips have wooden derricks, without any special method of transportation of material.

A very interesting set of observations were made on a ship during launching in regard to the conditions of hogging and ragging at different periods of the launch. These observations were facilitated by the arrangement of the deck houses, which had a break near the middle of

the ship. During wedging up, to bring the weight of the ship on the sliding ways, there was a little sagging. As the ship slid down the ways this sagging at first increased, then diminished, and changed to hogging as the ship became water-borne. At the leaving of the ways there appeared to be considerable vibration or rapid changing from sagging to hogging.

The establishment of Sir William Armstrong, Whitworth and Company, at Elswick on the Tyne, near Newcastle, is most noted for its extensive ordnance and armor-plate works. The extensive shops of this part of the establishment are on the bank of the Tyne, at various levels, as the configuration of the ground makes necessary. The shipyard on a narrow flat at the river's edge is an old yard, somewhat inconveniently arranged in consequence of its compression between the river and the ordnance shops on the bank, and further appears at some disadvantage in consequence of old and poorly arranged and lighted shops. A public road, which formerly ran between the yard and the ordnance shops, has recently been acquired by the company, and extensive improvements are in progress.

The ordnance and armor works of this company early placed them in position to build warships complete, with armor and guns, and their reputation has been widely extended by a number of remarkable ships of great power and speed for their displacement. Such ships have been bought by foreign nations, especially those that were unable to build for themselves, and which, to meet special conditions, found it desirable to be able to show large offensive power in proportion to their expenditures. The company has also built many ships for the British Admiralty and for foreign nations, which fill every requirement for service under all the ordinary conditions of powerful navies. It is most remarkable that this company has furnished two chief constructors to the British Admiralty, the one now in charge of the construction department and his predecessor. Both were trained in the government dockyards and at the Royal Naval College, and both loyally responded when the Admiralty needed their services.

This yard has four slips suitable for building large ships, two of them with a large slant down stream and two with the same slant up stream, this arrangement being due to the narrowness of both the yard and the river. The bending slabs and ship tool house are between the slips and the plate yards are outside the slips. Transportation within the yard is mainly on rails having the standard gauge, and largely by locomotive

cranes, already described in connection with the report on the yard of William Doxford and Sons. Three locomotive cranes bring material within reach of wooden derricks ranged alongside of the slips. All side armor is placed on ships by these derricks before launching.

It is the habit at this yard to assemble the armored deck of a warship in the mold loft and to templet all the topsides above the armored deck in the loft, so that this material can be ready in advance and thus facilitate construction. All framing behind armor is treated in a similar manner. Large holes are left where armor bolts are intended to be located, to allow the bolts to come or go as the sockets for them in the armor may require. Small plates are fitted over the bolts to cover these holes, and are riveted to the framing behind armor after the armor is in place. The system of templeting is carried to a large extent, the company making the templet instead of allowing the ship fitters to make templets for themselves, as is a common custom. At the time of my visit a large cruiser was building under secret service, so it could not be examined or even approached too closely; the same condition was found in another yard; but as special permission is required to examine warships under construction in private yards, whether building for the Admiralty or for foreign nations, and as that permission is always difficult, the only special interest was that not even the ownership of the vessel was given. Both ships have since proved to be ships carrying eight 12-inch guns, with a speed in excess of that of the *Dreadnought*. Though called cruisers, they are more powerful than any battleships now in active service. This cruiser was reported to have two rudders, so that a stern torpedo tube could be installed; the stern port consequently becomes a bent structure made of 7/8 or 1 inch plating. These ships are reported to carry the guns in turrets so arranged that four guns could be trained directly forward and two directly aft, while all eight can be trained on either broadside; and as no guns fire over another gun station, it is probable that the inboard turrets are arranged *en échelon*. This report is of interest in that the American arrangement of two central line turrets forward and two aft was spoken of with approval, it being said that such a device had been in part worked out though never applied. Another item of interest is that in ships built for the Japanese navy the magazine for cartridges was placed beneath the shell rooms, as the latter were found the more susceptible to explosion by external mines. To guard against the influence of mines, a 60-pound plate was worked under the magazines.

The yard of Swan and Hunter, at Wallsend, was the last one in this neighborhood to be visited. The general arrangement of this yard appears to have grown up with the growth of the yard, which is now combined with the adjacent yard of Wigham and Richardson, and does not present any notable feature, except that the yard appears too restricted in width for the very large ships under construction, which reach from the water front to the inland boundary wall. The most interesting features of the yard were the large glazed ship sheds over the largest ships. These sheds carried traveling cranes of the types described in connection with the yard of William Doxford and Sons, namely, a number of trolleys run the length of the shed, each with a swinging jib crane. This type of crane was designed for this yard by an American firm which builds hoisting machinery. At one side of each slip the ship house had a wide aisle, in which were the ship tools for serving that ship—a very convenient arrangement, made possible by the extent of their water front, and believed to be unique. It called to mind the method, first seen at La Seyne, of placing ship tools in the open between ships.

At this yard the ships are faired on marble slabs, only the scrive board and stem and stern being left for construction on the mold loft floor. A very large table was prepared for the large turbine Cunarder, which was then on the stocks. They had also tried opal glass without satisfaction, samples being shown which were thin and with too smooth a surface, on which the ink ran. It is interesting to compare this with our own successful experience with a very thick opal glass, which had a surface ground to conform to our specifications after trying samples. This glass is very strong, takes pencil and ink lines readily, and can be cleaned with ordinary soap and water, while a special powerful soap is required for marble. This glass is also much cheaper than marble, and obtainable in very large slabs.

The Fairfield Ship and Engine Company's yard, at Govan, on the south bank of the Clyde, is a good example of an established yard that has grown with the growth of shipbuilding and has been reconstructed to meet growing requirements. The arrangement of the yard is determined by the direction of the river front, which here runs somewhat to the north of west, with a turn toward the north at the lower end of the yard. As the river is narrow, the building slips have a sharp slope down stream, and extend nearly from the eastern boundary of the yard to the northwest corner; beyond the slips is the fitting basin, at the northwest corner of the yard. This arrangement leaves a triangular space at the northeast corner of the yard, which is used as the storage for plates,

frames, and beams, and which is served by two gantry cranes, one running at right angles toward the water fornt, and one parallel to the water front. The ship tool house with bending slabs, etc., lies across the inner end of the slips, so that material comes conveniently from the plate and frame store, and then is sent down to the slips. The engine and boiler shops are in the southwest corner of the yard, and the work from there goes northward down to the fitting basin. The cabinet and joinery shops, etc., lie between the building slips and the machine shop. There are two forge shops, one for the machine shop and one for ship work. Large forgings and castings are all made elsewhere.

The building slips are served by wooden derricks and electric winches, a method that is widely used in Great Britain. Material is brought from the railway station over the tramway rails by an electric locomotive that takes the current from the overhead trolley wires. The custom in this yard is to lay down all the ship's lines in the mold loft, and to make templets from those lines to a very large extent.

The Leven Shipyard of William Denny and Brothers, at Dumbarton on the Clyde, is an establishment of moderate extent, arranged in a simple manner for doing work of high order in an economical manner. The fact that they established the first private experimental model station, and that they have used it for twenty-two years for solving new problems in shipbuilding, is a guarantee that all their methods are selected deliberately and with good reason. The only exception to this, if indeed it has been allowed to have a controlling influence, is the general arrangement of the yard to suit the configuration of the site. For example, the building slips are arranged to point directly up the river Leven, into which the ships are launched, and they consequently radiate from a point instead of lying parallel; the angle subtended by the slips is, however, not large. This arrangement might make it difficult to use overhead traveling cranes, but the company have a system which they consider to be more economical and more effective; namely, they have a system of narrow gauge rails for small hand trucks, which run through the yard and into the shops. This system is extended down the slips and is moved wherever necessary by a special gang of men. As soon as the double bottom of a ship is laid, one or more lines of this system are laid on top, and in like manner lines are laid on decks as soon as convenient; of course the trucks readily run down such lines, on account of the inclination of the building ways. At the side of each slip is a hydraulic derrick for heavier weights, and there is a complete service of wooden derricks and hydraulic winches. A casual inspection of the yard, especially if

there should be no ship at a stage of construction that would show the system, might lead to a hasty conclusion that the yard lacks a transportation system. In addition there is a system of rails of standard gauge, with locomotive cranes of the usual type.

The system of templeting in the mold loft is carried to a considerable extent, but is supplemented by laying out the plates for bulkheads on the scrive board and making them so that they can be punched without using templets. To show that the system is capable of rapid work, it is said that the yard built a freight ship of good type, with some passenger accommodations, for the volunteer fleet of Russia, in six months.

The yard of John Brown and Company, at Clydebank, is another example of growth which has resulted in an apparent lack of system of storage and transportation of material. They have, however, a system of rails of standard gauge with locomotive cranes, and use the same method as at the Leven yard, of narrow gauge rails and hand trucks. Save for this feature (if indeed it is allowed to seriously interfere with the efficiency of work) this yard has the most modern methods introduced wherever they are considered advantageous. For example, they have an extensive application of direct electric driving of large tools of all sorts, and of groups of small tools, and they use converter gas for heating and power. They are equipped with large and accurate machinery for building steam turbines both for their own ships and for other builders, and had, at the time of my visit, a large amount of work in hand in all stages, so that there was a good opportunity to see the construction of large marine turbines of the Parsons type, including turbines for the large Cunarder now under construction. Incidentally it may be mentioned that in the construction of these monster ships European builders consider it essential to do a large part of the hull riveting with portable hydraulic riveters, and that a large stack of them was seen in the yard. The climate on the Clyde, though frequently inclement, does not give such low temperatures as are common on our seaboard, and there is no difficulty in using hydraulic transmission of power.

At this yard they depend mainly on laying down the ship's lines on the mold loft floor, though they have a marble slab which they have used to some extent for smaller work.

There was installed at this yard two years ago an experimental mold basin closely copied after that at Haslau, as is described in another report.[1]

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[1] TECHNOLOGY QUARTERLY, 19, No. 4, December, 1906, pp. 339–353.

One of the most interesting features of this yard is the production of converter gas for the heating furnaces and for generation of power in internal combustion engines of large size, which drive dynamos for the system of electric transmission of power. The essential feature of this system appears to be the use of a cheap coal with a considerable percentage of nitrogen, as much as 3 per cent. being considered essential for economical operation of the plant. This nitrogen, which is recovered as a by-product, is used as a fertilizer, and has the effect of reducing the net cost of coal from a dollar and a half to seventy-five cents a ton. The coal appeared to be a fairly clean bituminous variety, broken quite uniformly into rectangular pieces about half an inch square. This low fuel cost, with the small consumption by internal combustion engines, reduces the cost of power to a very low figure, and there is a corresponding advantage in the use of gas for heating furnaces.

The establishment of William Beardmore and Company, at Dalmuir on the Clyde, is a good example of a modern shipyard laid out *ab initio* with all modern appliances. The plan of this yard shows that it occupies a narrow strip of land over a mile long between the river and the railway. The yard is scarcely yet completed, and has done comparatively little work, so that it appeared under somewhat unfavorable condition at the time of my visit. Of the six slips shown on the plan, only one was in complete working order, and on it was a battleship for the British Admiralty. It had an overhead crane system without a roof, there being two traveling cranes to serve the two sides of the ship, and also a number of jib cranes distributed on the sides of the framework, under the traveling cranes. There were also two comparatively small ships, one each side of the battleship, without any special system for handling material.

The very extended water front (Fig. 5) gives a considerable dispersion to the various elements of the yard, but the arrangement shown appears otherwise to be very convenient. Thus the timber sheds are in the most remote section of the yard, together with the sawmill and timber pond; a fire in this region could easily be localized. The angle bars are stored at the right and the plates at the left of the building slips, while the bending slabs, ship tool house, and shipsmith shop, etc., are along the boundary in front of the building slips. The fitting basin is toward the western end of the yard, and around it are grouped the woodworking and plumbers' shops and stores on the right, and the machine and boiler shop at the left, with the central power station intermediate

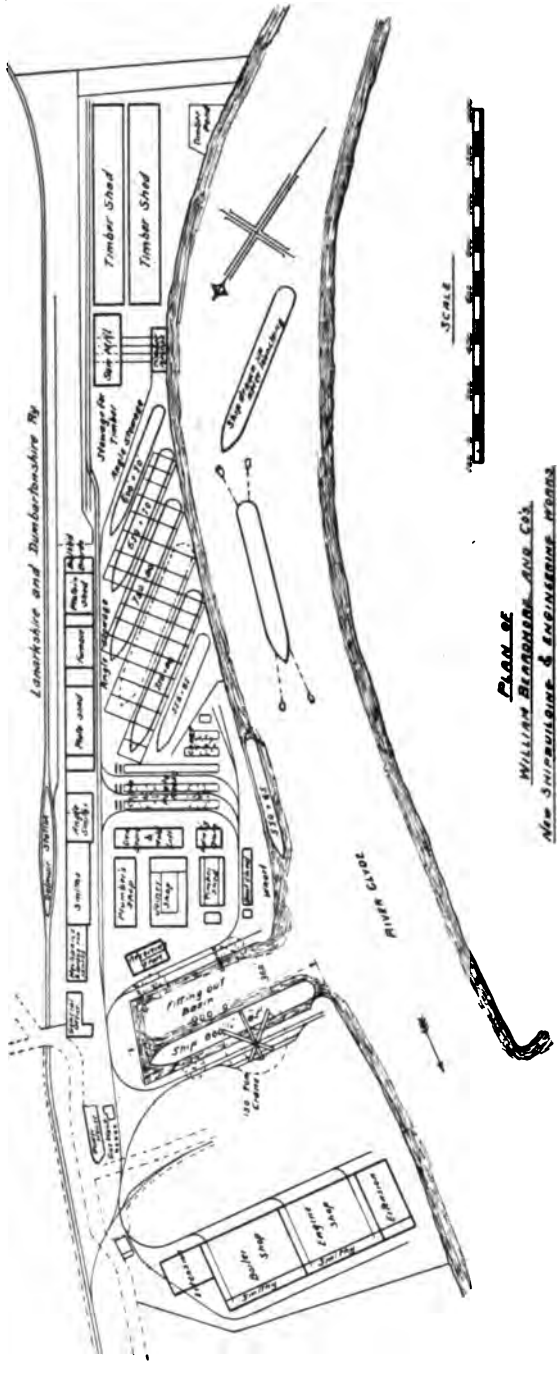
Timber Shed
Timber Shed
Lanarkshire and Dunbartonshire Ry
River Clyde
Scale
Plan of
William Beardmore and Co's
New Shipbuilding & Engineering Works
Balloch, Scotland

Fig. 5

between the various shops that require power from the system of electric distribution. There is room in the fitting basin for two large ships, and a third can lie at a wharf near the woodworking shops. At the basin is a crane for putting engines and boilers, etc., on board. This crane is a cantalever crane, with a short arm that can lift 150 tons and a long arm with great reach that can lift 50 tons.

The engine and boiler shops are in one immense, lofty building that is as yet unfinished. At the time of my visit the boiler shop was not divided from the engine shop, which was in consequence open to the noise and dirt of the former; but that may be a temporary arrangement. There was a provision of traveling cranes, and all large tools were driven by direct electric transmission. This yard, like that of John Brown and Company, has the converter system of making gas for heating furnaces and for power. Some of their engines generate a thousand horse power in four cylinders, having the pistons connected to two cranks.

The last yard visited was that of Harlan and Wolff, at Belfast. It is an old yard, noted for building ships of the largest size. Being situated on the bend of a river, it has some building slips looking up stream and some looking down stream; the plate and angle stores and the various shops lie between or along the street front. The engine shops are on the opposite side of the street. This yard was the first to introduce hydraulic riveting of the frames of large ships, and for this purpose placed over the slips lofty gantry cranes for carrying the portable hydraulic riveters. Two of the slips have an overhead cantalever crane of the Brown Hoisting Machinery type, which has the peculiarity that on each side under the cantalever crane there are traveling bracket cranes that can carry hydraulic riveters. Up stream from the building slips are several fitting slips or wet basins, and also a dry dock.

DETERMINATION OF SULPHUR IN PYRITE[1]

By HENRY FAY

I. Available Sulphur — Lunge Method

Spread out on the bottom of a 200 cc. casserole 0.4 to 0.5 gram of pyrite which has been ground to extreme fineness. Pour over this 20 cc. of a freshly made mixture of three volumes nitric acid (sp. gr. 1.42) and one volume hydrochloric acid (sp. gr. 1.20). Cover the casserole with a watch glass and warm gently until action commences; then remove from the heat until action slackens. Start the action again from time to time and remove from the heat when the oxides of nitrogen begin to be evolved. In this way continue the heating until all action has apparently ceased. Complete disintegration should be accomplished in five to ten minutes. If sulphur separates it is probable that the reaction was allowed to proceed too violently, or that the pyrite was not ground finely enough. In case sulphur has separated it is preferable to start with a new sample rather than to try to oxidize the separated sulphur by the addition of potassium chlorate.

When disintegration is complete add 5 cc. of sodium carbonate solution, and evaporate to dryness on the steam bath. Pour over the dry mass 5 cc. of hydrochloric acid (sp. gr. 1.20) and again evaporate to dryness. Moisten the residue with 1 cc. of concentrated hydrochloric acid, warm gently for a moment, then dilute with 100 cc. of hot water. Filter, wash several times with hot dilute hydrochloric acid, and finally with hot water.

Pour the filtrate into a slight excess of ammonia and keep the mixture hot for ten or fifteen minutes. Filter through a 4-inch Swedish paper, wash first by decantation, and then, throwing the precipitate onto the paper, wash thoroughly with hot water.

If the filtrate and washings exceed 250 cc., acidify with hydrochloric

[1] Editor's Note. — From time to time it is proposed to publish, with critical comments, various analytical methods which have proved useful in the Chemical Laboratory.

acid and concentrate approximately to this volume. To the boiling, slightly acid solution add a hot solution of 5 per cent. barium chloride from a dropper, allowing the drops to run down the inside of the beaker until a slight excess has been added. Allow to stand in a warm place for half an hour, then filter, washing by decantation with hot water until the washings are free from acid, and then complete the washing on the filter until free from chlorides.

When the filter has drained as much as possible from wash water, fold it over the barium sulphate, and place it in the bottom of a weighed platinum crucible. Incline the crucible on its side, with the lid partially covering the front, and place under the front end a flame so small that it will dry the paper so slowly that there is no danger of spattering, and that it will char the paper without taking fire. When the paper is completely charred, place under the back of the crucible the full oxidizing flame of a Tirrell burner, and heat thirty minutes. As some of the barium sulphate is invariably reduced to sulphide, it is necessary to allow free access of air into the crucible, and to continue the heating until constant weight is obtained.

II. Total Sulphur — Fresenius Method

Mix 0.4 to 0.5 gram pyrite with ten parts of a mixture of four parts sodium carbonate and one part potassium nitrate in a platinum crucible.

Cut an opening in an asbestos board (at least 4 inches square) sufficiently large to allow the lower two-thirds of the crucible to project below the board. Place the covered crucible in this opening, heat gently at first, and finally raise the temperature enough to bring the mass to fusion. Any unnecessary increase in the heat should be avoided on account of the action of the oxidizing mixture on the platinum. Keep the mass in fusion fifteen minutes, stirring, if necessary, with a stout platinum wire to prevent the fusion from caking on the sides of the crucible.

When the action has apparently ceased, place the crucible in a porcelain casserole, and extract the residue several times with boiling water. Decant the solution through a filter paper and then boil the residue with 20 cc. of a 10 per cent. solution of sodium carbonate. Finally, wash the residue thoroughly with a 1 per cent. solution of sodium carbonate.

Make the filtrate distinctly acid and then add 5 cc. of hydrochloric

acid (sp. gr. 1.20) in excess. Boil to expel the carbon dioxide and evaporate to dryness. Moisten the residue with 5 cc. concentrated hydrochloric acid and again evaporate to dryness. Then warm the residue gently with 2 cc. of hydrochloric acid (sp. gr. 1.20) and add 100 cc. of hot water; filter, and wash the silica.

In the filtrate, which should amount to about 250 cc., the sulphuric acid is precipitated in boiling solution by hot barium chloride, as recommended above, and the barium sulphate should be filtered, washed, and ignited in the same manner.

NOTES

1. The very great commercial importance of pyrite makes the accurate estimation of sulphur one of the most important determinations in the whole field of analytical chemistry. For the determination of *available* and *total* sulphur, the methods of Lunge and Fresenius, respectively, are undoubtedly the most accurate. The Lunge method determines only that portion of the total sulphur which is available for the manufacture of sulphuric acid; the Fresenius method determines all of the sulphur irrespective of the form in which it exists. Very many other methods have been proposed, but none of them has met with such general favor as these two, and they can at this time be considered as standards for this determination.

2. If the reaction in the Lunge method is allowed to begin too vigorously there is invariably a separation of sulphur, and, while it is possible to oxidize the separated sulphur, it is only done at the expense of much time and after the addition of considerable potassium chlorate.

The Lunge method cannot be used for the decomposition of many of the native sulphides on account of the strong tendency of some of them to liberate their sulphur in the free state. By using pure fuming nitric acid, or by reversing the proportions of nitric and hydrochloric acids, the decomposition and oxidation of most sulphides may be accomplished successfully.

3. It is necessary in all cases, before precipitation of barium sulphate, to remove completely all traces of nitric or nitrous acids by repeated evaporation with hydrochloric acid. It was shown as early as 1842 by Mitscherlich that barium sulphate carried down many salts from solution; on the other hand, its complete precipitation is inhibited by the presence of certain salts. In either case, when an accurate determination of sulphur is to be made, the salts which interfere with

the precipitation must be removed before barium chloride is added to the solution. Among the more common substances which are carried down with barium sulphate are the chloride, nitrate, and chlorate of barium, sodium, and potassium; copper, zinc, iron, and aluminium salts. Some interesting experiments have been made by Hulett and Duschak,[1] showing the amounts of barium chloride actually carried down with the barium sulphate. They have also devised a very simple method by which corrections can be made for this error. The complete precipitation of all of the sulphuric acid in solution is interfered with by the presence of chromium salts, metaphosphoric acid, etc.

4. The precipitation of barium sulphate in the presence of ferric iron has received attention from a large number of investigators. It has been known for a long time that low results are obtained when barium sulphate is precipitated from solutions containing ferric iron, notwithstanding the fact that the precipitate is contaminated with ferric oxide. In the process of ignition sulphur trioxide is lost, and the amount lost more than counterbalances the weight of the ferric oxide. The old method of fusing the ignited precipitate, if it showed a red color, led to inaccurate results, although ensuring a purer precipitate. Some of the sulphuric acid was always lost during the process of ignition, the amount depending upon the time and temperature of heating.

Various remedies have been proposed in order to overcome the difficulty of the precipitation of barium sulphate in the presence of iron salts. These remedies may be classed under three heads:

(1) Removal of the iron before precipitation.

(2) Conversion of the ferric ion into a complex ion.

(3) Conversion of the ferric ion to the ferrous ion.

The Fresenius method is the best representative of the first principle. In this case the iron is completely removed as the oxide, and, after the subsequent removal of nitrous and nitric acids by evaporation with hydrochloric acid, the precipitation may be carried out under the most favorable conditions.

In the Lunge method this same result is reached by precipitation of the iron by means of ammonia. Many chemists have claimed that this precipitation of ferric hydroxide always gave inaccurate results on account of the retention of basic iron sulphate in the ferric hydroxide precipitate. Lunge has repeatedly expressed the firm conviction, however, that if the method is carried out as he directs there will be no loss

[1] Zeit. für Anorg. Chem., 40, 196.

on this account. Gladding[1] modified the method so as to obviate the tedious washing of the ferric hydroxide precipitate. He recommended to redissolve the ferric hydroxide in hydrochloric acid and then the addition of barium chloride to this solution to recover the small amount of sulphuric acid carried down.

The most interesting modification of the Lunge method involving the same principle is that of Küster and Thiel.[2] They advised the precipitation of the ferric ion by an excess of ammonia and the addition of barium chloride to this solution, dissolving the ferric hydroxide after the complete precipitation of the barium sulphate. This method overcomes the objection raised by Gladding, in that it removes the iron from solution, and furthermore it does away with a troublesome filtration. The results obtained by this method are undoubtedly higher than those obtained by the Lunge method. Whether or not this is due to a certain counterbalancing of errors remains to be seen after further experiments have been tried. It is highly probable that the occlusion of barium chloride by the precipitation of the barium sulphate in the ammoniacal solution would be considerable. Lunge[3] has recently admitted and shown by a series of experiments that his own method gives accurate results only because of a counterbalancing of errors.

The conversion of the ferric ion into a complex ion was first suggested by Jannasch and Richards,[4] who used for this purpose formic, acetic, and citric acids, and this was extended by Küster and Thiel,[5] who used oxalic and tartaric acids; but in neither case were the results entirely satisfactory, as the precipitates were invariably colored by occluded iron.

The conversion of the ferric into the ferrous ion also originated with Jannasch and Richards,[6] but the results by this method have not been entirely satisfactory. When zinc and hydrochloric acid are used for the reduction, the zinc in solution is always carried down by the barium sulphate. In the hands of some chemists this method has been more satisfactory, although it has not come into general use.

No completely satisfactory explanation has yet been offered as to why barium sulphate carries down iron salts nor why solutions contain-

[1] J. Amer. Chem. Soc., 16, 401.

[2] Zeit. für Anorg. Chem., 19, 98.

[3] Zeit. für Angew. Chem.

[4] J. Prak. Chem., 147, 325.

[5] Zeit. für Anorg. Chem., 19, 101.

[6] J. Prak. Chem., 147, 322.

ing iron salts will retain some barium sulphate. Some evidence has been offered by Jannasch and Richards[1] for the existence of a barium ferric sulphate, and this idea has been subjected to experimental study by Schneider,[2] who came to the conclusion that a solid solution of low concentration was formed. On the other hand, Ostwald[3] has called attention to the analogy with chromium salts, which on heating form a complex ion containing the SO_4 group, which does not react with barium ions. Küster and Thiel[4] developed this idea and assumed that some such complex as $Ba[Fe(SO_4)_2]_2$ is formed, but they admit from the data at hand that it is impossible to say what is the nature of the complex. It seems probable that the true explanation will be that barium sulphate is capable of forming a solid solution with some product of the hydrolysis of ferric sulphate.

5. The explanation of the occlusion of barium chloride is very much more satisfactory. Hulett and Duschak have carefully determined the amounts of barium chloride carried down by barium sulphate under varying conditions, and have offered an explanation of this occlusion which seems to be satisfactory. They have found that barium sulphate carefully washed and dried at 140° contains not only barium chloride, but also chlorine in some form of combination which splits off hydrochloric acid at higher temperatures. Reasoning by analogy, they assume that barium chloride may, like lead and mercuric chlorides, dissociate not directly into Ba and Cl ions, but the dissociation may take place in this way:

$$BaCl_2 \rightleftarrows BaCl^{\cdot} + Cl'$$
$$BaCl^{\cdot} \rightleftarrows Ba^{\cdot\cdot} + Cl'.$$

In like manner sulphuric acid may also dissociate:

$$H_2SO_4 \rightleftarrows HSO_4' + H^{\cdot}$$
$$HSO_4 \rightleftarrows SO_4'' + H^{\cdot}.$$

On the assumption of such partial dissociation, $BaCl^{\cdot}$ ions could combine with HSO_4' ions to form the salt $BaCl.HSO_4$, which, upon being sufficiently heated, would split off hydrochloric acid and leave neutral $BaSO_4$. Hulett and Duschak also assumed the possibility of such reactions as the following to take place:

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[1] J. Prak. Chem., 147, 332.

[2] Zeit. für Phys. Chem., 10, 425.

[3] Zeit. für Phys. Chem., 29, 340.

[4] Zeit. für Anorg. Chem., 25, 322.

$$\text{I.}\quad 2BaCl^{\cdot} + SO_4'' \rightleftarrows \begin{matrix} BaCl \\ BaCl \end{matrix}\!\!> SO_4.$$

$$\text{II.}\quad 2HSO_4' + Ba^{\cdot\cdot} \rightleftarrows \begin{matrix} HSO_4 \\ HSO_4 \end{matrix}\!\!> Ba.$$

When the salt $\begin{matrix} HSO_4 \\ HSO_4 \end{matrix}\!\!> Ba$ is heated it should give off sulphuric acid and leave barium sulphate; when heated together with more than the equivalent of $\begin{matrix} BaCl \\ BaCl \end{matrix}\!\!> SO_4$, hydrochloric acid should form; and when heated with less than the equivalent, then we should expect both hydrochloric and sulphuric acids. This condition was actually realized by Folin,[1] who studied the conditions under which either one or the other of these two salts should form. He also suggested the possibility of formation of salts of the character represented by the formula $\begin{matrix} M'SO_4 \\ M'SO_4 \end{matrix}\!\!> Ba$ in which M represents any metal. This would account for the carrying down of potassium when barium sulphate is precipitated in its presence.

6. Too long and too high heating of the fusion in the Fresenius method will cause considerable attack upon the platinum crucible, and consequently the introduction of platinum into the analysis. If other constituents than sulphur are to be determined, this fact must be taken into consideration, and the platinum removed accordingly.

The completeness of the reaction may be judged by the appearance of the residue after fusion. It should have the color of rouge. If black, it will contain ferrous sulphide.

The use of coal gas for heating the crucible is almost unavoidable in a large laboratory, but in small laboratories the use of an alcohol lamp is strongly advised. The deflection of the products of combustion by means of an asbestos board partially overcomes the difficulty.

That barium sulphate is easily reduced to sulphide during the process of ignition is not sufficiently recognized. As much care should be used in the ignition of this precipitate as in the ignition of magnesium ammonium phosphate.

It should also be remembered that under no circumstances is it permissible to heat barium sulphate over the blast lamp. Above 900° it loses sulphur trioxide, and the residue becomes alkaline, owing to loss of sulphur trioxide.

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[1] J. Biol. Chem., 1, 131.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION

A METHOD FOR TESTING AND COMPARING SEWAGE SPRINKLERS[1]

BY EARLE B. PHELPS

IN the application of sewage to the surface of filters of the trickling or sprinkling type, evenness of distribution is an essential factor. This is more especially true in the case of filters whose material is of so coarse a nature that there is little or no lateral movement of the sewage within the bed. If on such a filter one-third of the surface is receiving two-thirds of the applied sewage, it is quite evident that the rate of filtration on that area is twice the mean rate. This rate would largely determine the character of the effluent, and an effluent of the same character could be obtained at twice the rate of filtration if the sewage could be distributed in a perfectly even manner over the whole area.

To accomplish this distribution over the surface of coarse-grained filters, many types of distributor have been devised. Among the more important of these may be mentioned: (1) Systems of fixed troughs, designed either to overflow or to discharge through notches or orifices; (2) delivery arms rotating over circular beds, operated either by the flow of the sewage or by power, distributing through nozzles or by overflowing; (3) large overflow troughs moved laterally back and forth over the bed; and (4) fixed sprinkler heads (pressure sprinklers) discharging upward under pressure, or discharging downward (gravity sprinklers) upon sprinkling or spattering disks. The distribution effected by these various methods is necessarily more or less uneven, and the efficiency of a given system may be defined as the evenness of the resulting

[1] Reprinted from Engineering News of October 18, 1906, LVI, 410–411.

distribution, a perfect distribution being one in which each small unit of area is receiving its proportionate share of the sewage. Such a condition is approached, in theory at least, by well-designed distributors of the second and third types enumerated. Their efficiencies depend upon proper leveling, unobstructed openings, and other details of design and operation which need not be gone into. Distributors of the first type mentioned cannot give perfect distribution. They distribute in lines, and as these lines are brought nearer and nearer together the distribution becomes more nearly perfect. In the Stoddart distributor the limit is reached and almost perfect distribution achieved by completely covering the filter with corrugated sheets of metal, the individual troughs being in actual contact. It is with the last group mentioned — pressure and gravity sprinklers — that the present discussion has to deal. Such sprinklers are fixed at definite points at or above the surface of the bed, and are designed to throw the sewage in a spray or spatter over the intermediate areas. The efficiency of their distribution under given conditions of head is determined entirely by their design, and the study of this efficiency is one which lends itself readily to careful experimental methods. The distribution is obviously not a perfect one, if for no other reason than that it is circular, and there must either be overlapping of the circles or intermediate non-wetted spaces, or both. Within each circle, moreover, there is generally a tendency to the formation of concentric rings of greater or less flow than the average, so that if small units of area are studied there will be found a variation in rate of flow along a radius. The definition of perfect distribution is one which is easily grasped, but the conception of a quantitative measure of the unevenness of the distribution is not so simple, and no attempt has heretofore been made to work out such a measure. Obviously the distribution is not measured by the wetted surface, although that expression is the best one which has thus far been used to describe the efficiency of a sprinkler. In the course of an investigation of pressure and gravity sprinklers now being made at this station, the need of some quantitative measure of the results was at once manifest. A mathematical analysis of the conditions involved was made, resulting in the definition of a "coefficient of distribution," which shows the mathematical relation between any observed condition of distribution and that condition which has been defined as perfect. In view of the ever increasing importance which sprinkling filters are assuming in this country, it is thought wise to publish this preliminary description of

the methods of testing employed and of the mathematical analysis of the results. A graphical representation of the conditions of distribution is first worked out, and from it the definition of the "distribution coefficient" is derived.

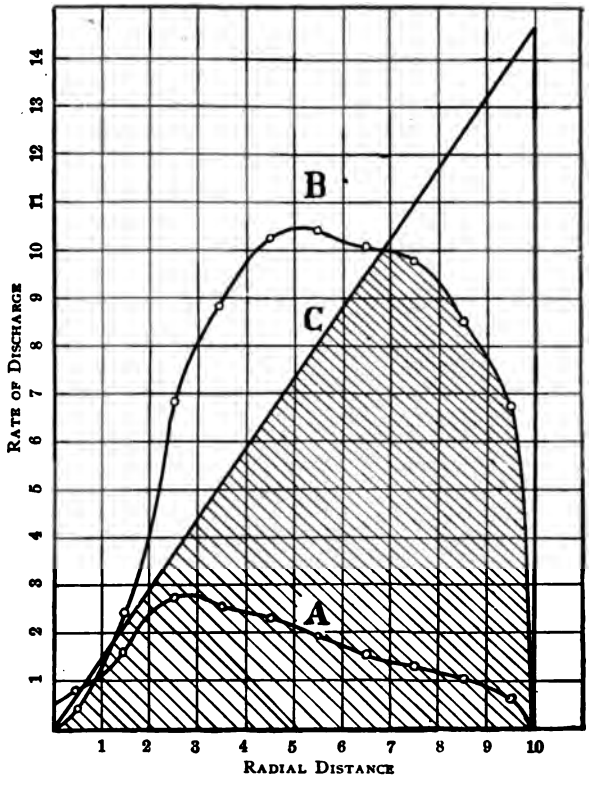
For the purposes of this problem let us assume that a pressure sprinkler is shooting up a spray of sewage, fountain-wise, the sewage falling over a circular area. Along any radius let us place a line of small, square collecting tanks of known areas, which we may designate the unit area. Let it be assumed, further, that the distribution along this radius is the mean of that along all radii. The variations along the various radii will be small, and the assumption may be completely realized, as is being done in our experiments, by revolving the line of collecting tanks about the centre during the experiment. After running a suitable length of time the sewage is shut off and the amount collected in each small tank is measured. In the accompanying table a set of actual results is reproduced for the sake of illustration.

TABLE SHOWING RESULTS OF OBSERVATIONS OF DISTRIBUTION EFFECTED BY SEWAGE SPRINKLER

Tank No.	Radial distance (D).	Sewage quantity (Q).	D × Q.	Excessive Quantities (Ex. Q).	D × Ex. Q.
1	0.5	0.8	0.4	. .	. .
2	1.5	1.6	2.4	0.14	0.21
3	2.5	2.7	6.8	1.24	3.10
4	3.5	2.5	8.8	1.04	3.65
5	4.5	2.3	10.3	0.84	3.78
6	5.5	1.9	10.4	0.44	2.43
7	6.5	1.5	10.0	0.04	0.26
8	7.5	1.3	9.8	. .	. .
9	8.5	1.0	8.5	. .	. .
10	9.5	0.6	5.7	. .	. .
Totals	50.0		73.1		13.43

$$73.1 \div 50.0 = 1.46 = \text{M}.$$

In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being



proportional to the volumes. Now if these quantities, Q, are plotted as ordinates against the corresponding D values as abscissæ, we obtain a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram. It shows the rate of discharge per unit area at any point whose distance from the centre is known, and will be known as the curve of radial distribution. Since the radial distribution measured was assumed to be the mean of all radial distributions, the ordinate of this curve at any given distance from the

centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i. e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing, relatively, by the radial distance of the point in question. In column 4, D × Q in the table, are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the corresponding D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

From its construction this curve has the following properties: the ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre; the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i. e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter. The base of the triangle is known, and from that and the area its altitude may be computed. It may be calculated more readily but less accurately by adding up the column Q × D and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area, which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the

more nearly will the two curves coincide and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves, differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

If we define the term "excessive discharge" as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form,

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities, $Q \times D$, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coördinate lines vertical, as usual, and the other set radiating from the origin. Direct plotting of the figures used in curve A upon such paper will in reality give curve B, any given value having an actual magnitude upon the plot which is proportional to the horizontal distance from the origin.

While the plot as thus worked out is essential to a clear understanding of the conditions and of the definition of the coefficient, it has been found much simpler and sufficiently accurate in practice to calculate the coefficient from the observed data (see table). Adding up the column $Q \times D$ gives the area under curve B, representing the total discharge (T). Adding the column D gives a number representing the

total wetted area; that is, it bears the same relation to the total area as the sum of the Q × D column does to the total discharge. Dividing the former by the latter gives the mean discharge (M) per unit area for the whole filter. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in the table under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column, they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total excessive discharge as already defined (E). We have now the two factors T and E for use in the formula,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

In the illustration used,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true coefficient based upon the total area of the filter, portions of which between the circles may not be wetted. Each sprinkler must then be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the final coefficient, C, may be found from the former coefficient, c, by the formula,

$$C = c \times \text{Cir/Sq}.$$

By the use of such a distribution coefficient it is possible to make experimental comparisons of both pressure and gravity sprinklers of various designs, and to test the effects of variations in head, rate of discharge, and other variables upon the distribution.

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BUILDING WARSHIPS BY CONTRACT; AND THE DUTIES OF THE SUPERINTENDING NAVAL CONSTRUCTOR[1]

By NAVAL CONSTRUCTOR A. W. STAHL, U.S.N.

WHILE general notions as to the proper composition of the fleet, and hence as to the character of new ships that should be built, are to a certain extent determined and settled by discussions in the various technical societies more or less directly interested and in the public press, as well as among naval officers in general, the formal and definite schemes for the actual ships to be built at any time are prepared by two boards in the Navy Department—one known as the General Board, and dealing largely with questions of strategy and war plans in general; and the other, the Board on Construction, consisting of the chiefs of certain Navy Department bureaus. When these two boards agree, their recommendation is practically always accepted by the Secretary of the Navy and transmitted to Congress; but when, as is unfortunately often the case, they disagree, the Secretary is under the necessity of coming to his own decision in the matter.

The Navy Department having recommended that certain ships be authorized, the matter is taken up by the Naval Committee of the House of Representatives. That committee gives hearings to the representatives of the Navy Department, as well as to others interested, and then recommends a certain building program for the session, this recommendation being necessarily influenced by many considerations other than that of obtaining the most efficient and necessary ships for the navy. The report of the committee is then considered by the House, which finally passes the Naval Appropriation Bill, in which bill are incorporated the descriptions of the ships to be built. This bill is then sent to the Senate, and by the latter body is referred to its own naval committee, which recommends that the Senate either concur in the bill, or, as is more usual, that the bill be modified in important particulars. The bill is finally,

[1] Lecture delivered to the Assistant Naval Constructors, at the Massachusetts Institute of Technology, Boston, Mass., December 8, 1906.

in some shape, passed by the Senate; and, if there are disagreements, it is referred to a conference committee between the two houses, and is finally adopted by both with a definite provision for certain ships.

The provisions enacted by Congress are not in detail, but simply in general terms, specifying the general character and size of each ship, its speed, and the limitation as to cost. Congress further provides whether the ship is to be built by contract or at a navy yard, and in some cases it gives the department the option as to these two methods of construction.

As soon as the bill has passed, the various bureaus of the Navy Department begin work on the plans and specifications of the particular ship or ships to be built. The plans are determined on, in a general way, by the Board on Construction, but the actual detail plans (except those of motive machinery) are made by the Bureau of Construction and Repair, being submitted from time to time to the board and modified as may be found necessary. At the same time, specifications are likewise prepared by the Bureaus of Construction and Repair, Equipment, Ordnance, and Steam Engineering. The Steam Engineering specifications are bound up separately; the specifications of the other three bureaus are bound in a single book known as the "Hull Specifications." In this book the Equipment specifications form a distinct and separate chapter, but the Ordnance requirements are simply embodied as a number of paragraphs in the Construction and Repair part. The plans and the specifications are finally approved formally by the Secretary of the Navy, and are then ready for issue to such shipbuilding firms as desire to bid on building the ship.

In the meantime, public advertisement has been made of the fact that on a certain day bids will be opened in the Navy Department for building the ship referred to; and the shipbuilding firms, who in response to such advertisement make application, are furnished by the Department with what is known as the "bidding circular." This circular recites the act of Congress authorizing the construction of the ship, and states the various limitations put on the size, speed, purchase of material abroad, price, etc., by Congress, and also gives the principal dimensions and other main features of the new ship. As soon as practicable, these builders are also furnished with copies of the specifications and plans of the vessel. The various shipbuilding firms then have their experts go over these plans and specifications, so as to become entirely familiar with the requirements of the prospective contract; and finally the men in authority

decide on the bid each firm will make. The methods of arriving at such bidding prices are different with every firm, and are governed by many other considerations besides the mere cost of the work to be done.

On the date specified, the bidders assemble at the Navy Department; and all bids are opened and read aloud in the presence of the bidders, the Secretary of the Navy, the Judge Advocate General, the chiefs of some of the bureaus, and other interested persons. If all the bidders base their bids exactly on the Government plans and specifications, the awarding of the contract is a very simple matter, as the law requires it to be awarded to the lowest responsible bidder; but this simple state of affairs does not usually exist. The bidding circular usually permits, or even invites, bidders to submit their own plans and specifications in competition with those of the Government; or, if not desiring to go to that extent, to propose modifications of the Government's plans or specifications, in each case giving their bid in connection therewith. When this condition of affairs exists, it is necessary, before the contract can be awarded, that careful study be given to the various propositions submitted by the bidders, in order that it may be determined which of these propositions, if any, it is to the advantage of the Government to accept. For this purpose the plans, specifications, and bids are referred to the Board on Construction, and by this board the various propositions are thoroughly examined. The board finally makes a report to the Department, recommending that the contract be awarded to some particular firm, on the basis of some definite proposition and price; and unless there be some exceptionally strong reason to the contrary, the board's recommendation is approved by the Department and the contract is formally awarded to the firm specified.

The next step is the signing of the contract; on the part of the Government by the Secretary of the Navy, and on the part of the contractors by the president or other duly authorized officer of the firm.

As soon as the contract has been signed, the Navy Department appoints certain officers as Superintending Constructor, Inspector of Machinery, Inspector of Equipment, and Inspector of Ordnance, in connection with the building of the vessel. Where the firm is already building some ships under contract, the various inspectors already on duty are always appointed for the new ship.

As soon as the contractors have signed the contract, the hull contract plans and specifications are sent to them through the superintending constructor, while the corresponding machinery plans and specifications

are furnished through the inspector of machinery. The contract plans are forwarded in the shape of Van Dyke prints. The superintending constructor first marks and signs these Van Dykes so that they can be identified at any future time. He then makes, in his own office, several sets of prints, after which he forwards the Van Dykes to the contractors.

The work of building the ship is now ready to be proceeded with, both the contractors and the constructor having the contract plans and specifications. Of the constructor's duplicate sets of prints, one is filed away as the official copy of the contract plans; the others are used for checking purposes.

The first thing done by the contractors is to have a very careful comparison made between the bidding plans and the contract plans; for although in theory these two sets of plans are identical, yet in actual practice it sometimes happens that modifications have been made before the contract plans are actually issued. Similarly the specifications are carefully scrutinized, and especially so the one particular copy which is marked and considered as the official contract specification. This would seem almost unnecessary, but in my own recent experience a case occurred in which some twenty or thirty pages had been accidentally left out by the binder from the particular copy of the specifications which was considered the contract copy.

If the contractors had reasonable grounds for expecting to get the contract, their drafting room would have the main requisitions for material all prepared and ready to send out by the time the contract was signed. The reason for this haste is that in the present state of the steel industry it is a matter of great difficulty to get early delivery of material, and hence it is very important to order the material at the earliest possible moment. These requisitions for material, as well as all the many others that must be prepared later, are submitted by the contractors to the constructor; and if they cover material to be inspected at the place of manufacture, the constructor forwards them to the Bureau of Construction and Repair. The purpose of this procedure is, first, to acquaint the Bureau with the status of the work and with the kind of material the contractors are preparing to use; and, second, so that the Bureau may appoint an inspector at the steel mills or other place of manufacture to examine the material as it is produced. At the same time the contractors send another copy of this requisition direct to the manufacturing firm, with their order for the material. When material is ordered by the contractors on the basis of a plan which has already been approved by

the constructor or by the Bureau, the Government cannot subsequently make any changes in the plan which will render any part of the material useless, without at the same time paying the contractors for the extra expense thereby caused them. If, however, as is frequently the case, the contractors submit their requisitions for material before the particular plans have been approved, then these requisitions are forwarded with the distinct understanding that any responsibility for the failure of the requisitions to agree with the plans as they are finally approved must be borne by the contractors.

While these early requisitions for material have been prepared, the contractors' drafting room has been busy on the fundamental drawings showing the general arrangements and details of the main structural work. The general layout of such work is usually fairly well defined in the contract plans and specifications, but there is always a clause in the latter which makes it obligatory on the contractors to provide ample strength; and it is at this point that the first conflict between the contractors and the constructor is liable to occur.

The main duty of the superintending constructor is to see that the ship is built in accordance with the contract; and this duty may be broadly divided into two parts: first, to see that the plans issued to the contractors' yard set forth correctly the work to be done; and, second, to see that these plans are adhered to in the actual building of the ship.

The specifications require that no work shall be done except in accordance with duly approved plans; and they further stipulate that certain of these plans (which are definitely named in the specifications) shall be submitted to the Bureau for approval, while all others must be approved by the superintending constructor. Now the contract plans usually issued by the Government are only twelve or fifteen in number, but many hundreds of plans are actually needed in carrying on the work on each ship. All these plans are prepared by the contractors, and must be approved by the Government before they can be used in the yard.

In order that the superintending constructor may be able to act intelligently in the matter of passing judgment on these plans, his office is provided with a drafting room, in which there are employed a chief draftsman and such other draftsmen as the importance of the vessel and the number of vessels being built simultaneously will justify. Some of these are leadingmen, to each of whom is assigned a particular ship; the others are draftsmen of various grades, and to each of the more experienced of these is assigned some general subject, such as framing,

ventilation, drainage, ammunition handling, turret work, etc. When the contractors have completed a plan, they submit it to the superintending constructor, the plan being actually delivered to the constructor's chief draftsman. The latter, without examining the plan, assigns it to one of the draftsmen. This draftsman makes a careful detailed examination of the plan along the following lines: first, Is the plan in strict accordance with the contract plans and specifications? second, Is it in accordance with past practice? third, Is it a good plan? and fourth, Could it be improved? The draftsman's examination on the first of these points is based on the contract plans and specifications, copies of which are furnished him. It is his business to make a careful study of these plans and specifications, so that he may interpret properly what the exact requirements are. His investigation as to the second point is based on the corresponding plans of previous ships on file in the drafting room, the object being to determine whether the new arrangement is better or worse than has been previously used. The object of the third investigation is to make sure that if the plan is approved the work will prove satisfactory. This does not mean that it will necessarily be the best possible arrangement, but simply that it will work and that it will be strong enough. The last investigation is directed towards improvement in the plan, either by embodying practices that have developed since the Bureau's specifications and plans were made, or ideas that may have been suggested from other sources. The draftsman finally makes a memorandum of his criticisms of the plan, and submits the same to the proper leadingman. The latter goes over the plan with him and discusses with him the various points. The plan is finally turned in to the chief draftsman, with a written memorandum containing the criticisms of the plan and any suggestions as to its modification. The chief draftsman then makes a personal examination of the plan, more or less carefully and in detail, according to its nature and importance, basing such examination mainly on the memorandum referred to.

In case the modifications which he deems necessary are unimportant, or so clearly required as to admit of little discussion, he returns the plans to the contractors with a memorandum setting forth the changes desired. If, however, the changes are more important, he submits the plan to the constructor, with a verbal explanation of the points at issue. As a result of this discussion, he then sends the plan back to the contractors with a memorandum as to the changes desired. A copy of each memorandum is filed in the chief draftsman's office.

The plan having been returned to the contractors for revision, it remains with them either (*a*) to revise the plans as requested, (*b*) to induce the constructor to recede from his request or to accept some modification of the same, or (*c*) to appeal the case to the Bureau over the constructor's head. In unimportant matters the contractors usually yield without question; and this is also true in matters of more importance, but where the amount of money involved is not great. In larger matters the representative of the contractors has a verbal discussion with the constructor relative to the points at issue; and to this discussion is usually invited the chief draftsman, and, when the matter is complicated, also the leadingman and other draftsmen who have considered the plan in question. As the result of this discussion, the constructor either recedes from, or modifies, his request, or else he insists. In the latter case, the contractors have but two courses open, viz., either to change the plans accordingly, or to appeal to the Bureau. Which course they will follow depends mainly on the personality of the constructor.

The plan having been modified by the contractors, either according to the constructor's request, or to the Bureau's decision in case an appeal is made, is finally submitted to the constructor for approval. The latter then signs on the tracing a statement that the plan has been approved on a certain date for this particular ship, and then returns the tracing to the contractors; but before returning the tracing, he has made, in his own office, a blue print copy for his own file, as well as several additional copies for use in connection with the work of inspection.

The above procedure applies directly to plans which need be approved by the superintending constructor only. In case the plans must go to the Bureau for approval, practically the same course is followed before they are sent on to Washington, except that the superintending constructor does not insist on having changes made on the plans if the contractors object, but contents himself, when forwarding the plan, by stating to the Bureau exactly what demands he had made on the contractors which they had been unwilling to carry out. He also, at the same time, gives the Bureau his opinion of the plan, and recommends either that it be approved, that it be returned for revision, or that some other plan be made in lieu thereof.

The above procedure as to original plans applies in principle, also, to alterations made on plans that have already been approved. As the work proceeds, many changes in details are found necessary. These are usually first discussed between the representatives of the contractors and

of the naval constructor; and as a result of such discussion, the contractors formally re-submit the plan, showing on the same the alteration proposed, together with a note on the plan stating what the alteration is. When this alteration is approved by the constructor's signature in the alteration stamp on the plan, a new blue print is made for the drafting room file, or the alteration is formally entered on a print already on file.

The tracings having been finally approved and returned to the contractors, the latter make the necessary number of blue prints and issue them to the various yard departments. At the same time similar prints are issued from the constructor's office to his own representatives in charge of the outside work.

This outside work, *i. e.*, the work on the ships and in the shops, is usually in charge of the senior assistant constructor; and to assist him in the work he usually has one or two Carpenters and from three to six Special Mechanics. The Carpenters are warrant officers in the Navy, who have had experience on seagoing vessels and who are familiar with many details and conditions that might not be fully realized by men working continuously on shore. The Special Mechanics are, as the name implies, expert mechanics in their various lines, who act as sub-inspectors in matters of workmanship and other details. These men are appointed as a result of competitive examination. They are men of about the grade of foremen, and usually know thoroughly the details of the work for which they are employed.

The special mechanics usually attached to a superintending constructor's office are as follows: outside shipfitter, inside shipfitter or machinist, plumber, and shipwright. The outside shipfitter looks after the structural hull work in all its details; he also makes all tests for watertightness. The inside shipfitter looks after the installation of the turret and other guns, and all auxiliary machinery, except as to its electrical connections. The plumber looks after the drainage and flushing systems, the ventilation system, the galley, and other plumbing work. The shipwright looks after all the woodwork, including both deck and joiner work, and the painting.

The carpenters have direct charge over the special mechanics, and are themselves expected to look after matters of general arrangement, stowage, etc. In addition to these men, there is also employed an electrician, or, as he is called, an expert electrical aid, and it is his duty to look after all electric installations under the Bureau of Construction and Repair, and to make all tests of the same.

In actually carrying on the work, it has been found best to have the carpenters and special mechanics assemble every morning at a stated time in the office of the assistant constructor. At that meeting the carpenters and special mechanics bring to the attention of the assistant constructor any points which have come under their notice during the past twenty-four hours, while the latter, on the other hand, informs them of any decisions that have been reached, and gives them any other necessary instructions. The carpenters and special mechanics spend practically their entire time in the shops and on board the vessels, and the assistant constructor likewise spends much of his time in the same places.

I have so far described the manner in which the plans are examined and approved, and the means which are taken to ensure that the plans shall be followed in the construction of the ship. But in actually carrying out this scheme, a large amount of correspondence takes place, both with the Bureau and with the contractors; and to carry this on properly, there are provided a chief clerk, a file clerk, and a number of stenographers and typewriters. Owing to the fact that any question discussed or decided may at any time become important from a legal standpoint, it is necessary that proper and authentic copies of all correspondence shall be kept on file. To do this in connection with letters from the superintending constructor to the Bureau, in my own recent practice, such letters were written in quadruplicate; one copy went to the Bureau, one to the office file, one to the senior assistant constructor, and the other to the chief draftsman, the latter two copies being simply for their information and being subsequently destroyed. In the case of a letter written to the contractors, seven copies were made, four of which were sent to the contractors, and the other three distributed as before. The object in sending four copies to the contractors was to relieve them from the necessity of making copies for their individual files and other purposes. This was not a matter of regulation, but simply one of courtesy; and the same courtesy was extended by the contractors to me, in that, when they wrote me a letter, they furnished me with enough copies for my various files and other purposes.

The description of the work, above outlined, contemplates that the ship is built strictly in accordance with the contract plans and specifications. But while this is usually true of the main features of the ship, yet in many details changes are made, these being due sometimes to advances which have been made since the date of the contract, sometimes to change of policy on the part of the Navy Department, sometimes to

unsatisfactory reports that are received relative to the working of certain arrangements in actual service, and to many other reasons. Such a change is proposed by one of four parties, viz., the Bureau, the superintending constructor, one of the other inspectors, or the contractors; and the preliminary correspondence differs somewhat according to such origin. In its essential features, however, the correspondence agrees. The contractors submit a formal proposition in writing, either proposing the change and submitting their estimate of the amount whereby their compensation should be increased or decreased by reason of that change, or (if the change has not originated with them) simply submitting their estimate without any recommendation.

If the change pertains simply to the Bureau of Construction and Repair, the superintending constructor then makes his own estimate of the change in cost involved and forwards it, together with the contractors' estimate, to the Bureau, making at the same time such recommendation relative to the change as he may deem proper. If the change refers to work coming wholly, or in part, under the Bureau of Equipment or of Ordnance, the superintending constructor calls on the inspector of equipment or of ordnance for his estimate, and on receiving the same he includes it with the other papers to be sent to the Bureau. If the amount involved does not exceed $500, it is within the province of the bureaus to decide the question; but if the amount is larger than $500, the matter must be referred to the Secretary of the Navy. In either case, if the work is authorized, the Bureau so informs the constructor, and at the same time submits to the Board on Changes the question of the change in cost.

This board consists of three naval constructors; namely, a senior member, who is the same for all such boards at the various yards on the Atlantic coast; a second member, who is usually the senior assistant at the yard in question; and a third member, who is detailed for that duty from some near navy yard or private yard. This board meets at stated times in the office of the superintending constructor and considers the various changes that have been referred to it since the last meeting. When these changes refer to the Bureau of Construction and Repair only, the board of three naval constructors takes necessary action; but when any change comes wholly, or in part, under the cognizance of the Bureau of Equipment or of Ordnance, the inspector of such bureau is also a member of the board for that change.

A few days before the proposed meeting of the Board on Changes,

the senior member notifies the contractors, the constructor, and the other inspectors of the date of such meeting, and at the same time sends them a list of the changes which it is proposed to consider at that meeting. On the day of the meeting, as soon as the board has convened, the senior member obtains from a representative of the contractors a list of any changes on which the contractors desire to offer further argument; and when such changes are reached, the representative of the contractors appears before the board for that purpose. The superintending constructor is never a member of the board, but is called on by the board for any additional information the board may desire. The board, after further discussion, then votes on the amount of increased or decreased compensation, and submits a report relative to the matter to the Bureau of Construction and Repair. When that report has been approved by the Bureau in case the change in cost is less than $500, or by the Department in case the change is greater than $500, the case is settled and the legal right of the contractors to additional compensation in the amount specified, or, *vice versa,* the legal right of the Government to deduct the amount specified, is established.

Assuming that the work of building the ship is now regularly going on, it becomes necessary to consider the manner in which the contractors are paid for executing their contract. The contract provides that the contract price shall be divided into a certain definite number of equal parts (formerly usually thirty, but now usually fifty), and that the contractors shall be paid these equal installments as fast as they earn them, the fact of each installment having been earned being established by the joint certificate of the superintending constructor and the inspector of machinery to that effect. This certificate, so far as the superintending constructor is concerned, is based on figures and computations which, while not exact, are yet fairly close to the truth. Soon after the contract is signed, the contract price is, by mutual agreement between the Government and the contractors, divided into two parts: one part the machinery price, representing the portion of the work under Steam Engineering, and the other the hull price, representing the combined work under Construction and Repair, Equipment, and Ordnance. The hull price is again subdivided into about thirty items, such as drawings, structural steel, launching expenses, joiner work, handling armor, installation of battery, drainage, ventilation, anchor handling apparatus, painting, trial trip, etc., the portion of the hull price assigned to each of these items being based on past experience.

Now, from the calculations made during the designing of the ship, it is known approximately what the total weight under each of these items is; and by dividing the *lump sum* appropriated to each item by the corresponding *total weight,* we arrive at the *average cost per pound* under that item. Now, manifestly, the *actual* cost of any particular pound of such an item as ventilation varies very greatly according as we are considering, for instance, a pound of *sheet iron pipe,* or a pound of *electric motor.* Hence any system of estimating cost based on such weight units is of course liable to great error when applied to *individual separate* portions of the various items; but when that system is applied to the *weight totals* under the various items, the main result is *sufficiently close to the truth* for our purposes. In connection with the building of the vessel, an accurate record of all weights is kept; not the *estimated* weights, but the *actual* weight of every piece of material as it goes on the ship. These weights are entered in elaborate schedules, and many precautions are taken to see that nothing is omitted and that nothing is duplicated. These records are kept up continuously from the time the work on the ship is begun until she is completed; and while they are intended mainly to be used in connection with future designs, they are used during the progress of work in the computation of the amount of money earned by the contractors. This is done by ascertaining the actual weight completed under each of the thirty items above referred to, and multiplying each such weight by the average cost per pound of that item. This will give the amount of money earned by the contractors under each item; and by adding these amounts together we get the total amount earned.

In actually figuring up this amount, there are other refinements introduced. Certain amounts are deducted for work which has been weighed and placed in the ship, but which has not been entirely completed, such as, for instance, outside plating which has not been riveted up; and other amounts are added for work done in the shops which has not yet been weighed up. The cost of launching and the cost of trial trips are each put down as lump sums as these events occur; the cost of drawings is figured as a certain per cent. of several structural items.

When the grand total of the amount thus computed as having been earned under Construction and Repair, Equipment, and Ordnance, *plus* the amount which the inspector of machinery computes as having been earned under Steam Engineering, equals or exceeds one of the equal installments of the contract price, the superintending constructor and

inspector of machinery join in a certificate to that effect; and on the basis of that certificate, when approved by the respective bureaus and the Secretary of the Navy, the contractors are paid one of these equal installments. This scheme applies to all except the last three payments. These are not paid until after the ship has made a successful trial trip and has been preliminarily accepted; and even then there is still kept back a reserve of some thousands of dollars, held up to cover unforeseen contingencies and breakdowns. All this applies to the regular installments of the contract price; but there are other payments—those for authorized changes. Where these involve increases in compensation, the amounts determined by the Board on Changes are paid to the contractors on the certificate of the constructor that the work has been done. Where they involve decreases in compensation, the amounts are deducted from the final reservation.

As the work on the ship proceeds, it is subjected to continuous observation and inspection, and to tests designed to demonstrate its quality. In the early stages of the work, care is taken that frames and bulkheads are properly located, that the seams of plating come together properly, that rivet holes are fair, and that the riveting is properly done. As soon as the condition of the work warrants it, testing for water-tightness is begun. This is done by actually filling each compartment with water under a definite pressure, the head of water being obtained by means of a pipe screwed into the compartment and extending the proper distance above the base line. This testing is carefully done, and the seams and joints are gone over until the work is practically tight. As the work proceeds and auxiliary machinery is installed, more elaborate tests are made. Without going into details, it is to be noted that tests, representing the condition of actual service as nearly as possible, are made on the steering gear, turret operating gear, ammunition hoists, anchor handling gear, boat cranes, ventilation system, flushing system, drainage system, in fact, on all the items which enter into the efficient working of the ship. These tests are all made in accordance with a memorandum which the superintending constructor furnishes to the contractors as soon as practicable after work on the ship has begun, this memorandum being based on the specifications and any special instructions of the Bureau, as well as on past experience and practice.

By the time all this testing is well along, the ship itself is nearing completion. It is to the advantage of the contractors to run the official trial at as early a date as possible, and hence they usually apply for per-

mission to run this trial as soon as the machinery has had a successful dock trial and the work on the hull has proceeded far enough to warrant them in believing that permission will be granted. The contract requires that this trial shall not be run until the ship is completed and ready for delivery. This contract requirement, however, is never literally carried out, but is construed to mean that the ship is practically ready in all essentials and that the uncompleted work is either (*a*) unimportant, (*b*) work which cannot be done because of delays in delivery of material by the Government, (*c*) work, such as final painting, which must necessarily be deferred until after the trial trip, or (*d*) work which for some reason it is to the interest of the Government to so defer. When the contractors make their application for the official trial, the superintending constructor and the inspector of machinery make a report, stating whether or not, in their opinion, the ship will be ready at the time specified; and in this report, as well as in many other matters relative to the final completion of the ship, the superintending constructor represents not only the Bureau of Construction and Repair, but also the Bureaus of Equipment and of Ordnance. Unless some unexpected objection develops, the department authorizes the trial to be held on that date, and makes the necessary arrangements in connection with the appointment of a board to witness and report on such trial.

Just before the trial, the ship is always placed in dry dock, for the purpose of cleaning and painting her bottom; and at this time it is customary for a member of the Trial Board to arrive at the contractors' works to inspect the ship's bottom. When such member does not come, this inspection is made by the superintending constructor and reported to the Trial Board. In the meantime the constructor is preparing a list of unfinished work, made out in as much detail as possible. This list is usually quite lengthy, though many of the items are unimportant; but as it forms the basis of the Trial Board's report relative to unfinished work, it is important that it be as nearly right as possible. I have been in the habit of making a *preliminary* copy of the list about ten days or two weeks before the trial, and furnishing the same to the contractors so as to enable them to make objection to any items if they see fit. By this course, any matters in controversy can usually be settled before the official list is made. Finally, the day before the ship is to leave on her trial, the list is brought up absolutely to date; and numerous copies of the now *official* list of unfinished work are made and furnished to the Trial Board, the contractors, and the other inspectors. The senior

assistant constructor usually goes on the trial as the representative of the superintending constructor, and carries with him one of the carpenters, certain special mechanics, one or two draftsmen, the electrician, a stenographer, and such other help as he may deem necessary.

While the trial is primarily to determine whether or not the ship fulfills the contract requirements as to speed, strength, stability, manœuvring qualities, etc., yet the Trial Board also reports at length on two other points, namely, (*a*) the unfinished work required by the contract and authorized changes, and (*b*) any changes and improvements which in the board's opinion are necessary or desirable.

As soon as the ship returns from her trial she is thoroughly cleaned, and work is immediately begun by the contractors towards finishing up the various items of work given in the official list of unfinished work. While this is going on, the report of the Trial Board is referred by the Department to the superintending constructor for comment; and on the basis of the latter's recommendations the Bureau and the Department come to a decision as to any changes to be made, or any other matters in dispute, the result of all this being definitely to establish and settle just what work must be done before the ship is delivered. As this work proceeds and draws near completion, the contractors inform the Department that they will be ready to deliver the ship on a certain day, and ask that it be duly received. Unless there be objection raised by the inspectors, this delivery is usually authorized on the date requested by the contractors.

Immediately previous to that date there are placed on board the ship all the various articles of equipage and supplies that have been delivered for her, and on that date she is towed to the navy yard specified in the contract. The commandant of the yard gives a receipt to the contractors for the ship, and takes charge of the ship as a whole; but the representatives of the contractors remain with the ship for some days, until all the miscellaneous portable articles are checked up by the representatives of the Government and of the contractors, when the contractors obtain a receipt for these also.

Soon after this the ship goes into commission; and this usually results in numerous complaints being made as to certain items of work, as well as numerous changes being suggested, by the officers of the vessel. All of these are referred to the superintending constructor for recommendation, and when he has finally submitted his report on these points he has finished with the ship so far as her construction is concerned. There still

remains the final financial adjustment, which is deferred until the constructor finally reports that all work has been completed except certain definitely specified items, which for some reason cannot be done and for which a certain amount should be deducted from the contract price. The above course is sometimes varied by putting the ship in commission at the works of the contractors.

To successfully fill the position of superintending constructor, several qualifications are necessary. In the first place, there is the extensive *knowledge of detail,* which is gained only by experience. It is, of course, to the contractors' interest to build as cheaply as possible, and thus all contractors are continuously endeavoring to modify details of construction in that direction. It is the constructor's business, on the other hand, to see that the details are entirely satisfactory. While this work is mainly accomplished through the medium of examination and criticism in the drafting room, yet the *personal* knowledge of detail possessed by the constructor is a very large factor in keeping down the number of plans submitted by the contractors for the mere purpose of cheapening the construction.

Another important quality is *quickness of decision.* In an establishment employing, as most of these private yards do, thousands of men, time is very valuable; and it is important that, when the contractors submit a proposition, they be given a prompt answer. In some cases the matter of time is so important that the contractors would really prefer an adverse decision given immediately rather than a favorable decision given at some later date.

Another essential quality is *firmness,* which, however, must not be carried to the limit of obstinacy. Having once announced his decision, the superintending constructor should not change it, except for *very good* cause. It greatly facilitates the work if it is thoroughly understood that when a matter has once been decided, it is to be regarded as settled.

Another important quality for a superintending constructor to cultivate is a *judicial temperament;* and in this particular there is a tendency among men, when first assuming duty at a private yard, to become possessed of the idea that the interests of the contractors and of the Government are diametrically opposed, and that any hardship they can inflict on the contractors results in a corresponding gain to the Government. It must not be forgotten that there are two sides to almost every question; and if the superintending constructor will approach disputed questions with the idea of ascertaining the truth, rather than with the

idea of upholding the Government side at any cost, he is much more likely to achieve success.

And lastly, one of the most important things is the cultivation of harmonious and pleasant *personal relations* between the constructor and the other inspectors and the representatives of the contracting firm. With such relations and a willingness to discuss disputed points on their merits, without introducing any personal element, it will be found that the work will progress more rapidly and more efficiently, to the greater advantage of the Government, and to the greater credit of the superintending constructor.

THE AIR OF THE NEW YORK SUBWAY PRIOR TO 1906

BY GEORGE A. SOPER

Read November 22, 1906

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INTRODUCTION

THE object of this paper is to record some hitherto unpublished facts concerning the quality of the air of the New York subway before any material change was made in its ventilating arrangements, and to seek to explain the essential conditions which controlled it.

The data were collected during an investigation of the subject, covering six months, which the Board of Rapid Transit Commissioners for the city of New York requested me to make in June, 1905.

The original data, largely in tabulated form, together with various reports, covering in all about one thousand pages of typewritten manuscript, have been in the possession of the board since February, 1906. Most of these data will probably never be printed.

Being assured that a fuller account of the methods and conclusions than had hitherto been published might be of service to engineers, I have, at the request of the Society of Arts, prepared the review of the investigation which constitutes the following paper. The Board of Rapid Transit Commissioners has courteously given its consent to this use of the facts.

ACKNOWLEDGMENT OF ASSISTANCE

It was through the intelligent and skillful efforts of the persons who were called upon to aid in the investigation that the results were in large part due.

The average number of assistants continuously engaged on the work was ten. From first to last, there were twenty-one persons officially connected with the investigation; about two-thirds of this number were technical school graduates.

Especially capable work was done by Floyd J. Metzger, Ph.D., in the chemical analyses; by Clinton B. Knapp, M.D., and Payn B. Parsons, M.D., in the bacteriological studies; and by George S. Frost, C.E., in the meteorological observations. Aid of an unusually competent character was given in the studies of ventilation and in compiling the data by Mr. John P. Fox.

Valuable counsel and other assistance was given by a number of the author's friends who were not officially connected with the investigation. Most of these were professors in Columbia University. Among them may be mentioned Dr. Charles F. Chandler, Professor of Chemistry; Dr. T. Mitchell Prudden, Professor of Pathology; Dr. William Hallock, Professor of Physics; and Dr. Philip Hanson Hiss, Professor of Bacteriology. To these and others whose help added accuracy and value to the investigation, I desire to express here my sense of appreciation and thanks.

SCOPE OF THE INVESTIGATION

The principal questions investigated related to temperature, humidity, odor, bacteria, and dust. The conditions found in the subway were compared with the conditions found in the streets through which the subway runs, and occasionally with conditions in other places.

In studying each subject, my plan was to obtain an accurate knowledge of: First, the conditions which existed; second, the causes of these conditions; and third, what, if any, remedy was required.

In seeking to explain the causes of the conditions, it was necessary to take account of the sanitary care which the subway received from the company which operated it and the manner in which ventilation was accomplished.

In two of my official reports, the only ones printed, and in a paper

read before the New York Academy of Medicine, March 15, 1906, the character of the sanitary supervision was described and specific recommendations made for improving it. Little will be said here concerning this matter. Inasmuch as the way in which the subway was ventilated has never been fully described, a brief description of it will be given.

No attempt was made to devise a comprehensive system of ventilation or cooling to improve the air. Experiments in this direction were being made by the regular engineering staff of the commission. I merely studied the effects of these experiments and reported upon them.

My single expression of opinion with regard to cooling the subway was that substantial benefit would result if more and larger openings were made between the subway and the outside air, and that improvements to the cars might prevent the production of the excessive amount of heat through a more economical employment of the power. The first of these suggestions was made early in the investigation. Its correctness has since been fully demonstrated.

In all, there were about 2,200 chemical analyses of air, 3,000 determinations of bacteria, and about 400 other analyses in special studies of dusts, oils, disinfectants, and other substances. About 50,000 separate determinations of temperature and humidity were made prior to the adoption of a system for automatically and continuously recording temperatures throughout the length of the subway and in the streets.

The methods employed in studying the different topics were, for the most part, such as had been used in other sanitary and meteorological investigations in which a considerable degree of accuracy was required. It is not claimed that they would have been the best to adopt in a purely scientific research. It was necessary to design them for practical as well as accurate use.

For the most part, the air to be analyzed was collected at an elevation of 18 inches to 2 feet above the pavement. This height was decided on as the most convenient and suitable, after an attempt had been made to collect it at the breathing line. Only by taking samples near the ground was it possible to avoid attracting curious crowds of persons whose presence would have rendered the samples valueless. Tests made of air from different elevations indicated that no substantial error was made in taking samples near the pavement.

Very few samples of air were taken in the cars. Persons familiar with the conditions of crowding in the cars of the New York subway at practically all hours of the day will appreciate the inconvenience with

which delicate and bulky scientific apparatus could be used among persons standing as close together as it was physically possible to stand. Furthermore, the question at issue was not whether the passengers in the cars obtained good air or not, but whether the air outside the cars was satisfactory.

ESSENTIALS OF CONSTRUCTION AND OPERATION AT THE TIME OF THE INVESTIGATION

The details of construction and equipment of the New York subway have been made the subject of so many extended and authoritative accounts that it is unnecessary to deal exhaustively with these matters here. It seems desirable, however, for the sake of clearness, to refer briefly to some of the features of construction and operation which bore directly upon the condition of the air at the time of the investigation.

Part of Subway in Operation

The part of the road which was in operation during the period of this investigation extended from the lower end of Manhattan Island northward to 96th Street and Broadway, where it divided, one branch continuing along Broadway to 157th Street, and the other eastward and northward until it crossed under the Harlem River and reached that part of the city known as the Bronx.

Nearly all of this road was underground. There was a short, exposed portion of a few blocks covering a valley at 125th Street, and the branch to the Bronx, after crossing the Harlem, soon emerged upon an elevated structure, which it did not leave to the end of the line; but the parts of the subway which were not underground were not considered in this investigation.

Section Chosen for Closest Observation

The length of the road, about 21 miles, and the rather wide variety of conditions which occurred in it made it desirable to confine the investigation as far as practicable to a representative section.

There was no difficulty in selecting this section. The road between 96th Street and the Brooklyn Bridge was, in every respect, the most important. Further on in this paper it will be shown that this section was divisible into two parts, distinct differences both as to details of

construction and the condition of the air being noticeable between the part north of 59th Street and that south.

Nearly all the studies recorded in this paper, except those of temperature and humidity, refer especially to the representative section between 96th Street and the bridge. In many cases, however, they have a much wider application.

The length of the section was about 6 miles. The cubic air space included was, in round figures, 26,100,000 cubic feet, including the stations.

The section was four tracks wide, excepting a piece of tunnel which ran between 42d Street and 34th Street. Here there were two tunnels of two tracks each, running side by side, cut through the rock.

Sanitary Features of Construction

By the contract we learn that it was intended, when the road was designed, that it should be easily accessible, light, dry, clean, and well ventilated.

It was partly to accomplish these ends that the road was built as close to the surface of the streets as physical conditions permitted.

Dryness.—Much care was taken to make the subway dry. It was declared to be the "very essence of the specifications" for construction to secure a structure which should be entirely free from the inward percolation of ground or outside water.

To accomplish this end, a practically continuous sheet of asphalt was built within the concrete bottom, sides, and top of the structure. This water-tight envelope consisted of from two to six thicknesses of asbestos, or other similar felt, laid in hot, natural asphalt. In addition, every part of the road was so drained that water finding access thereto was led away by natural drainage or automatic pumps to the city sewers.

Lighting.—The roof of the subway was so close to the level of the streets that it was possible for the builders to make extensive use of vault lights for illuminating the stations with natural light. Full advantage was taken of the possibilities in this direction. The lights were made of cast-iron frames, with lenses about 2½ inches in diameter of strong glass set in cement. The area of the vault lights at some stations was so great that little artificial light was employed, excepting at night.

Incandescent lamps were the only artificial lights used except for signals.

Provisions for Cleanliness.—In constructing the road, provisions for keeping the subway clean were carefully carried out at the stations. The platforms were made of cement and the walls of tile, the joints and moldings being such as to permit of easy cleaning. The stairways were supplied with safety treads, which collected much street dirt, thus keeping it from entering the subway.

Provision was made in the original design for a concrete roadbed,

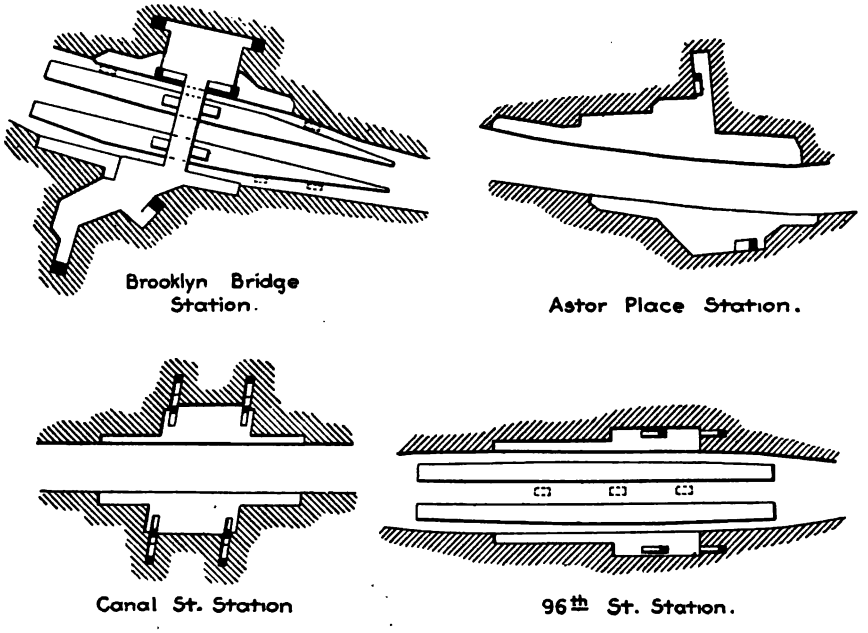

FIG. 1.—PLANS OF FOUR TYPES OF SUBWAY STATIONS SHOWING THE STAIRWAY OPENINGS TO THE STREET

which would have enabled the road to be kept clean between stations; but modifications in the contract, after it was let, resulted in the construction of a broken stone roadbed, from which only comparatively large particles of refuse could be removed.

Stations.—There were twenty stations on the section chosen for especially careful study. Most of them were situated outside of the railway, the two sides being duplicates.

With few exceptions, each side was equipped with two water-closets for the use of women and men, respectively. They were well furnished with bowls, hand basins, and sinks, each of which was supplied with a back-aired trap and connected with the sewer.

The closets were designed to be ventilated through ducts connected with the street above, and, toward the close of this investigation, electric exhaust fans were set in many of the ducts to force the air of the closets into the street. At the beginning of this investigation, ventilation was effected only through the doors communicating with the subway.

The express stations, of which there were five in the section especially studied, were larger than the local stations, and provided with platforms between the tracks. The express stations were about 1½ miles apart. They were: Brooklyn Bridge, 14th Street, 42d Street, 72d Street, and 96th Street. The plans of four types of subway stations showing the stairway openings to the street are shown in Figure 1.

Track.—The track consisted of the standard gauge roadway, with the wooden cross-ties and broken stone ballast, which is commonly seen on the best steam railroads out of doors. This type was adopted at the request of the operating company, after the general contract for the road had been let.

The original contract had specified that in the underground portions of the railway the tracks should consist of rails laid on a continuous bearing of wooden blocks, the grain of which was to be transverse to the length of the rail. The blocks were to be held in place by guard rails secured to metal cross-ties imbedded in the concrete floor.

Provisions for Ventilation

The subway was ventilated through the stairways at the stations and through blow holes in the roof.

Blowholes.—All of the blowholes which were originally built were located in that portion of the road which lay above 60th Street. They were rectangular in shape, and opened upon small grass plots which occupied the center of the wide boulevard known as Upper Broadway. Iron railings surrounded the openings. To prevent the entrance of large objects, the openings were covered with coarse wire netting.

The blowholes were located above the center of the railway, one being situated a little beyond each end of each station. An additional blowhole was placed midway between each two stations above 59th Street. The total number of blowholes between 59th and 96th Streets was eighteen. Each was about 7 x 14½ feet in the clear. Wire nettings, beams, and other objects took up about one-quarter, or more, of this space.

Stairways.—The stairways between the streets and the stations varied somewhat as to width and direction. Below 59th Street they were usually placed at right angles to the line of the road; above 59th Street they were parallel to the road. There were usually two stairways, each in cross section about 5½ x 7½ feet, to each local station above 59th Street, and eight narrower ones to the other local stations.

The stairways were covered with ornamental kiosks, which stood upon the sidewalks near the curbs. They were without doors. The

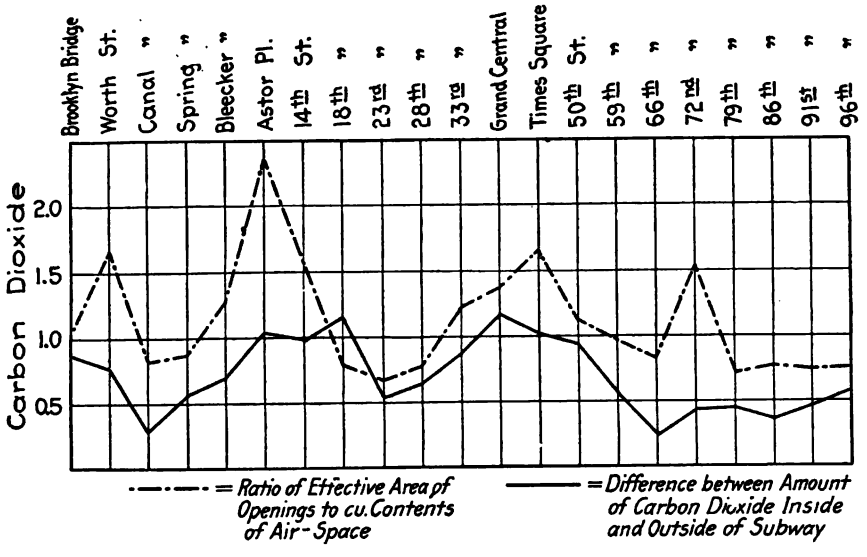

FIG. 2.—RELATION BETWEEN THE CHEMICAL CONDITION OF THE AIR IN THE SUBWAY AND THE RATIO OF THE EFFECTIVE AREA OF THE OPENINGS TO THE CUBIC CONTENTS OF THE AIR SPACE AT DIFFERENT STATIONS

kiosks opened north and south above 59th Street; below 59th Street they usually faced east and west.

The relation between the chemical condition of the air in the subway and the ratio of the effective area of the openings to the cubic contents of the air space at different stations is shown in Figure 2.

PHENOMENA OF VENTILATION

Exchanges of air between the subway and streets took place chiefly by reason of the movement of trains.

Effects of Train Movements.—The subway was about 50 feet wide

and 18 feet high on the four-track section between Brooklyn Bridge and 96th Street, and the cross section of a car occupied about 14 per cent. of this subway section. The trains were from 150 feet to 408 feet long.

The number of passengers in the cars varied somewhat at different hours of the day, but the cars were usually crowded. There were fifty-two seats in each car, and when the aisles and platforms were filled the total number of passengers per car ranged from about 115 to 140. The densest crowding occurred in the rush hours and throughout the length of that portion of the subway which was under closest observation.

The number of cars per train, the number of trains per hour, and the speed varied at different hours. The local trains usually consisted of five cars, and ran at a rate, exclusive of stops, of about 21 miles per hour. The express trains generally consisted of eight cars, and ran at a rate, exclusive of stops, of about 26 miles per hour.

The total number of passengers carried in the subway, as indicated by an official statement of the ticket sales, averaged, for the last two months of 1905, 440,000 per day. There were about twice as many passengers carried in November and December as in July (see Table I).

TABLE I

SHOWING THE NUMBER OF PASSENGERS CARRIED FROM EACH STATION OF THE SUBWAY FROM JULY TO DECEMBER, 1905, INCLUSIVE

(From the report of the Board of Rapid Transit Commissioners for 1905.)

	Number of passengers.
July	6,076,241
August	7,085,814
September	8,843,314
October	11,329,216
November	12,677,761
December	13,715,946

As a train moved through the subway, air was forced ahead of it and air followed it. As a rule, a general current flowed along the track on each side of the subway in the direction of the train movement, and these currents continued even when no train was within hearing distance. The important action of a train was to force air along with it, but where stairways or blowholes occurred and offered lines of diminished resistance, the air rushed out through them as a train approached and rushed in as the train went by.

The difference in barometric pressure necessary to set up these air currents was exceedingly slight; the effect of friction against the walls and pillars of the subway and the sides of the stairways considerable. A great part of the force with which the air currents were set in motion was generally used up in eddies about the trains.

The movement of the air depended upon the speed of the nearest train, the movement of other trains in the vicinity, the size and location of the neighboring openings to the outside air, the size of the particular cross section of the subway with reference to the sections of the moving trains, the force and direction of the wind in the streets with reference to the position of the stairways, the difference in temperature inside and outside of the subway, and other conditions.

The chemical analyses of air which were made gave data from which the frequency with which the air was renewed could have been computed had the number of passengers present at any corresponding time and part of the subway been known. Accurate information on this subject was not, however, available.

TABLE II

RESULTS OF COLOGNE EXPERIMENTS, SHOWING RATE OF PASSAGE OF AIR FROM STATION TO STATION

Points of Observation.	Distance Traveled.	Time Consumed.	Speed.
Stations.	Feet.	Minutes and seconds.	Miles per hour.
Worth Street to Brooklyn Bridge	835	5:25	1.75
Worth Street to Canal Street	910	1:15	8.27
Worth Street to Canal Street	910	7:35	1.36
Spring Street to Canal Street	1,540	5:30	3.18
Spring Street to Canal Street	1,795	10:10	2.00
Spring Street to Canal Street	1,795	12:20	1.66
Spring Street to Bleecker Street	1,230	3:40	3.81
Spring Street to Bleecker Street	1,230	5:25	2.58
Average	..	..	3.08

Anemometer Observations.—Observations with anemometers were made at a number of stations on several occasions. As a result of seventy-nine of these observations, covering, in the aggregate, two hours and thirty-five minutes, made at eight stations, it was calculated that an average of 573,000 cubic feet of air had moved in and out of one

stairway per hour. This was at the rate of 9,500 cubic feet per minute.

The maximum movement of air observed was when 63,000 cubic feet passed in at one station in one minute through a single stairway. The velocity of the current on this occasion was 16⅓ miles per hour.

Circulation of Air between Stations.—That the air circulated freely from one station to another was shown by CO_2 analyses (to be referred to later) and by noting the time that it took an odor to pass from one station to another. Cologne of a highly concentrated grade, and in sufficient quantity to produce a distinct perfume throughout the air of a station, was used at several points and the odor noted up and down the line with the help of assistants with stop watches. Care was used that the cologne should not be transported mechanically by coming in contact with the trains in liquid form. The results of the cologne experiments are given in Table II, and of CO_2 analyses in Table IV.

As a result of eight cologne experiments, it was found that the odor was carried from station to station at the average rate of 271 feet per minute, or about 3.08 miles per hour. The cologne vaporizer used in these experiments is shown in Figure 3.

Ventilation of the Subway and Human Lungs Compared.—The ventilation of the subway bears an interesting resemblance to the ventilation of the human lungs, and it will help to understand the former if we trace some of the details of this analogy.

The ventilation of both the subway and the lungs is due to currents of air passing inward and outward as a result of changes of pressure, caused chiefly by the expansion and contraction of the enclosed space.

It is true that with the lungs the size of the enclosed space is alternately enlarged and reduced through the movement of its walls, while in the subway the size of the enclosure is increased and diminished through what is termed the piston action of the trains; but in other respects the similarity is close.

In the normal amount of air which passes out of the subway on the approach of a local train, and is replaced by an indraught of fresh air as the train draws away, we have what physiologists, in speaking of the ventilation of the lungs, call the "tidal air." In the additional quantity which is drawn in by the express trains, we have the "complimental air," and in the excess which is forced out by express trains the "reserve or supplemental air."

These three, the tidal, complimental, and supplemental, we may term the "respiratory or ventilating capacity" of the subway.

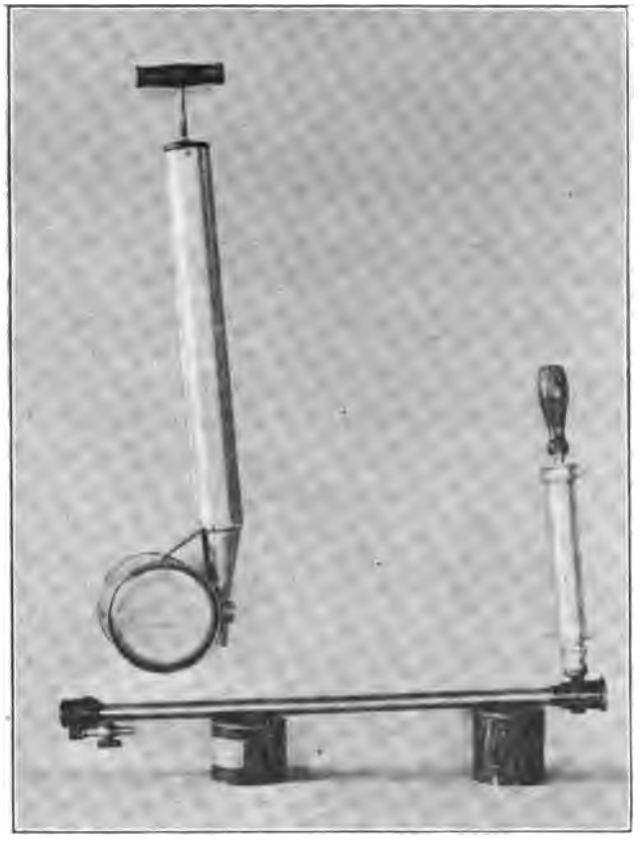

FIG. 3.—THE KONISCOPE (BELOW) AND THE COLOGNE VAPORIZER (ABOVE)

Finally, there is an amount of air which remains in the subway and is not immediately forced into the streets by any combination of local and express trains; this we may call the "residual air."

This terminology is appropriate and convenient for general purposes, and it is suggested that it should come into use among ventilating and sanitary experts in dealing with ventilation problems of much less strictly physiological character than those to which it has hitherto been confined.

TEMPERATURE AND HUMIDITY

From an early period in the construction of the road, an effort had been made to observe the temperature and humidity at a number of points by means of automatic, recording thermometers. Later, when

the sanitary conditions were being made the subject of investigation, these records were critically examined and the observations put upon a more exact basis.

In this section we will briefly review the early and later methods and the final system of observing temperatures, and then pass to a consideration of the results of all observations.

Methods Employed

The various methods employed may be conveniently considered separately.

Early Methods.—The earliest date upon which any systematic record of temperature or humidity was made in the subway was June 26, 1903. At that time a number of maximum and minimum thermometers and stationary wet and dry bulb hygrometers, with some small Richard thermographs, were placed in the subway at various places between the City Hall and Columbus Circle stations, at different points on the line above 50th Street, and outside.

The accuracy of the observations made with these instruments was carefully studied by me in July, 1905, with the result that the temperature records were found to be generally accurate, probably to within 5°, and the humidity observations to within 20 per cent. The readings were all generally too high.

Methods Used from July 1 to September 18, 1905.—After the work of observing temperatures and humidities came under my direction, no maximum and minimum thermometers nor stationary wet and dry bulb hygrometers were employed.

Temperature and humidity observations were first undertaken in this investigation on July 1, 1905. They were made with sling psychrometers designed as made for the United States Weather Bureau, with some minor changes intended to fit them especially for subway work.

The psychrometers consisted of two mercurial thermometers 24 cm. long, graduated from —10 to 125° F., fastened upon an aluminum back, 1½ cm. apart, centre to centre.

The bulbs projected beyond the aluminum back for about 5 cm., one of the bulbs being covered with cotton cloth. The upper end of the aluminum back was connected by two loose wire links, fitted by a pivot to a substantial handle around which the thermometers could be whirled.

To make it conveniently transportable, the whole instrument was fitted into a specially designed cylindrical aluminum case, and was there secured by a bayonet lock at the top. The case was arranged so as to hang from a leather strap, so that the instrument might be slung over the shoulder when not in use. The psychrometers were made by Schneider Brothers, 265 Green Street, New York.

The manner in which the sling psychrometer was employed and the tables used to calculate the humidity are contained in W. B. No. 235, issued by the Weather Bureau of the United States Department of Agriculture.

When tested at a testing station, established for the purpose of determining the accuracy of the various instruments employed in the investigation, the thermometers were found to be accurate to within one-tenth of 1° F.

Four observers were regularly employed in making the psychrometer observations. Each visited a given number of stations per day, between 9 A.M. and 5 P.M., and recorded the temperature and humidity inside and outside of the subway. The express stations were visited twice.

In making an observation at a station, the observer took into account the air throughout the entire length of the platform. It was usual to make five observations at about equal distances from one end of a platform to the other. Each observation consisted of at least four readings of the thermometers. The readings were recorded in notebooks to the nearest half degree.

At first sight it may appear that these data, obtained at only certain hours of the day, with the late afternoon and early morning left out, may give a misleading idea of the average temperatures for the twenty-four hours. This, however, is not the fact. Continuous observations carried on day and night for a week showed that the data so obtained, when worked into averages for days and weeks, gave an excellent knowledge of the conditions.

The total number of temperature and humidity observations to November 16 was about 50,000, considering the temperature and humidity observations separately.

Final System of Observing Temperatures.—The observations with sling psychrometers were not intended to furnish the data from which the most important deductions concerning the temperature were to be derived. The instruments selected for this purpose were thermographs.

The suitability of practically every well-known thermograph on the market was considered for this use. Specimens of five makes were set

up in the testing station and compared for several weeks before a choice was finally made.

The instruments chosen were the largest thermographs made by J. Richard, Paris. About one dozen of these were especially imported for subway use; others were obtained in America. The total number of thermographs which were put in use was twenty. On test they were found to be capable, under the practical conditions required, of recording changes of temperature to within one degree and time to within ten minutes, if visited daily and kept clean and adjusted.

As may be supposed, the thermographs never showed the changes of temperature which actually occurred. They were most accurate when the changes were slow and not very decided. To be precise, the thermograph curves could be interpreted as neither more nor less than the record of the net effect of several conditions, only the leading one of which was the temperature of the subway near the instrument.

Observations with a delicate mercurial thermometer showed that changes of temperature occurred in the subway of far greater extent and frequency than were indicated by the thermographs (see Fig. 4). But if they did not give a scientifically perfect record of every change of temperature, they were none the less serviceable. It was not desired to know each change, but only the more decided and lasting ones.

A special observer was trained to keep the thermographs in good condition, to check their readings with an accurate mercurial thermometer, to make necessary adjustments, to wind the clocks, and to renew the record sheets every week. The records were systematically filed.

The management of the thermographs and the observations of relative humidity were turned over to the engineering corps of the board on November 18, with the recommendation that the system be made permanent.

The thermographs were placed in specially constructed cages in the stations of the subway, generally at the end of the platform which was approached by incoming trains. They were as far removed as possible from local draughts, and about 4 feet above the pavement.

The thermographs located out of doors were placed in cages of similar construction to those used underground. The locations of the outside thermographs were selected with a view to having the instruments in the shade, remote from the effects of radiation from pavements and buildings, and beyond the influence of outrushing currents of air from the subway.

The records obtained from the thermographs gave an excellent idea

of the average differences in temperature which existed between the subway and streets and between one subway station and another. They also showed fluctuations in temperature which gave clews to the origin of the heat, to the extent and ways in which ventilation took place, to the movements of trains, and many other instructive matters.

Throughout the period of this investigation, observations of temper-

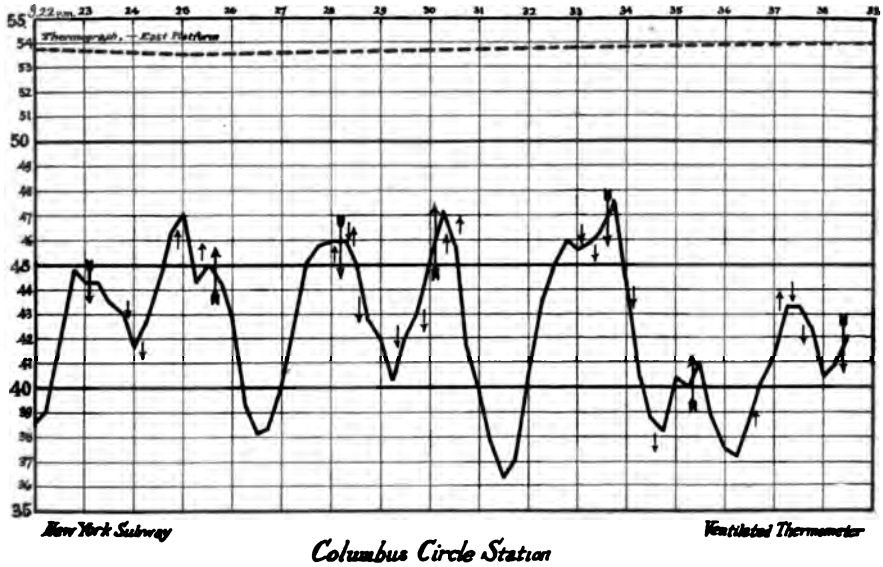

FIG. 4.—RAPID VARIATION IN TEMPERATURE NOTED, WITH A VENTILATED THERMOMETER, AND ACCOMPANYING TRAIN MOVEMENT. THE SMALL ARROWS SHOW THE MOVEMENT OF LOCAL, THE LARGE OF EXPRESS, TRAINS IN EACH DIRECTION

ature were made by the company which operates the subway. These observations consisted of hourly readings of ordinary tin-backed thermometers inside and outside of the stations. The thermometers were usually read by colored porters, few of whom were competent to do this work properly. None of these records is used in this paper.

RESULTS OF TEMPERATURE AND HUMIDITY OBSERVATIONS

Before the Subway Was Opened for Travel.—In view of the overheating of the subway which took place in 1905, it is interesting to

review some of the temperature characteristics of the road before it was thrown open to travel. In reviewing these figures, it must be remembered that the entrances, exits, and blowholes were more or less closed at this time, and that a free circulation of air in and out was correspondingly obstructed. Had all the openings been free, there would have been less difference between the inside and outside air.

During construction, and before the subway was covered by a roof, its temperature was practically that of the outside air.

After the roof was put on, marked differences occurred. The temperature of the subway was now much more constant than that outside.

Before trains were run, hourly and daily changes of temperature in the streets seemed to affect the subway but little. The more marked and continued changes, however, produced visible effects.

In winter the air outside was cooler, and in summer warmer, than the air of the subway. The total range of temperature of the subway air at 112th Street for the year August 6, 1903, to July 27, 1904, was from 22° to 68°, or 46°; while the range outside was from 2° to 94°, or 92°. In other words, the range of temperature in the streets was twice as great as the range in the subway.

During the hottest week in the subway, before it was opened, the temperature, according to the 112th Street records, averaged 59.4°, while the street temperature was 77.7°. At its hottest, the subway was 18.3° cooler than the streets.

The records of early temperatures in the subway give no idea of the normal temperature of the earth through which the subway runs. The temperature probably varies according to the depth under the surface, the presence or absence of ground water, the nature of the rock or earth, and other conditions. In the deep tunnel which runs under Central Park, a temperature of 54° was frequently observed in June and July, 1903, although the temperature outside at the same time occasionally reached 95°.

In the year in which the road was opened for travel, the subway at Columbus Circle (59th Street) averaged about 53° warmer than the average temperature in the streets.

In March and April the average temperatures inside and out were practically the same.

From the middle of April to the end of September, the subway at Columbus Circle was cooler than the streets.

Immediately after Opening the Subway to Travel.—From the middle of August until the opening day, October 27, 1904, the subway was gradually cooling from the highest point which it had reached in the summer. From that time to the end of the year the temperature gradually fell.

The large amount of travel which the subway experienced at the start did not visibly affect the decline of temperature which was to be expected at this season of the year.

For the first ten weeks of 1905, the subway was slightly warmer than in 1904. It is not clear that this difference was due solely to the fact that the road was in operation. The temperature out of doors was warmer than it had been the year before.

Beginning about the middle of March, or at that season when, in other years, the temperature inside and outside had been about the same, the heating due to the operation of the road first became distinctly visible. Instead of the streets becoming warmer than the subway, as had been the case the year before, the temperature inside rose also. Thenceforth a higher temperature in the subway became the rule, both winter and summer.

The Summer of 1905.—Throughout the investigation with which this paper is concerned, the subway was generally warmer than the streets. The only exceptions were when the outside temperature rose rapidly after a prolonged low period. This usually occurred in summer in the middle of the day, and in winter after a cold snap.

The excess of subway temperature over outside temperature increased considerably during the autumn and winter months. In the early part of July the difference between the temperature for the whole day inside and outside of the subway was less than 5°. In the latter part of September it was over 10°. In January, it was at some stations about 20°. An average daily difference, for a week, of 30° was found at one station.

Referring now to the observations of temperature made with the dry bulb thermometers of the sling psychrometers, we are prepared to obtain a better idea of the conditions which obtained in the summer after the subway was opened.

The subway grew warmer as the summer advanced. It averaged 81° through July, 1905. In the week of August 4 to 10, it was 83.4°. Thereafter it declined very gradually, until the latter part of September, when it was 76°.

In the week of September 29 to October 5, there was a slight rise to

78°, corresponding with a rise of temperature out of doors. This was followed by a more rapid decline than had occurred at any time before. Uncomfortably high temperatures were not again experienced in 1905.

During its hottest period the temperature of the subway followed the temperature of the outside air, except in the more extreme and rapid changes of the latter. This correspondence is seen to be most marked when the data for inside and outside are compared in the form of weekly and monthly averages (see Table III and Fig. 5).

The temperature in the subway for the daytime for July and August,

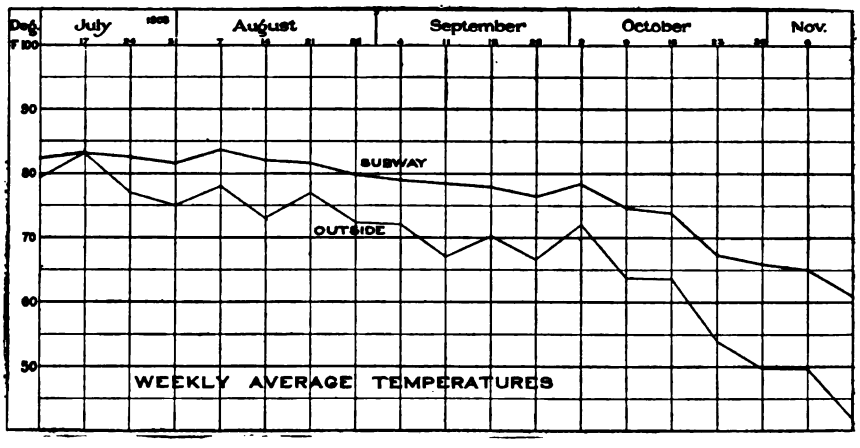

FIG. 5.—WEEKLY AVERAGE TEMPERATURES IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905. THESE AVERAGES ARE MADE UP OF 47,476 OBSERVATIONS

combining the records of these two months to form an average, was 82.4°; it was 76.8° outside; difference, 5.6°.

Highest Temperatures in the Summer of 1905.—The highest temperature observed in the subway during the investigation was 95°. This occurred at the Brooklyn Bridge station, July 18, 1905, at 3.50 P.M.

The hottest week was that of August 4 to 10, inclusive. The average daily temperature for the subway during this time was 83.4°; for the outside air, 78.2°; difference, 5.2°.

The maximum temperature observed in the subway during this hottest week was 88.2°; in the streets it was 88.2° at the same time.

The Warmest and Coolest Stations.—The coolest station was Canal Street, and the warmest Astor Place.

TABLE III

WEEKLY AVERAGE, MAXIMUM AND MINIMUM TEMPERATURE, AND RELATIVE HUMIDITY IN THE SUBWAY AND STREETS AS DETERMINED BY SLING PSYCHROMETER OBSERVATIONS FROM JULY 1 TO NOVEMBER 16, 1905. THE NUMBER OF OBSERVATIONS INCLUDED IN THIS TABLE IS 97,168

Date, 1905.	Place.	Average		Maximum		Minimum	
		Temperature.	Humidity.	Temperature.	Humidity.	Temperature.	Humidity.
July 1–13	Subway	83.3	61.5	90.0	95.0	74.0	30.0
	Surface	79.6	68.8	88.4	88.0	73.0	28.0
	Difference	3.7	7.3				
July 14–20	Subway	83.2	51.6	95.0	69.0	72.0	36.0
	Surface	84.2	48.7	100.0	80.0	71.6	32.5
	Difference	1.0	2.9				
July 21–27	Subway	82.4	50.7	90.6	85.0	70.0	31.5
	Surface	76.3	48.6	84.0	81.0	67.6	21.0
	Difference	6.1	2.1				
July 28–Aug. 2	Subway	81.2	55.7	88.6	91.0	67.0	28.5
	Surface	74.7	59.6	85.0	86.0	62.8	32.0
	Difference	6.5	3.9				
Aug. 4–10	Subway	83.4	64.4	88.2	86.0	71.5	52.5
	Surface	78.2	69.5	88.2	93.0	70.0	31.0
	Difference	5.2	5.1				
Aug. 11–17	Subway	81.5	59.0	89.0	85.0	69.5	34.0
	Surface	72.8	70.3	88.0	100.0	59.0	38.0
	Difference	8.7	11.3				
Aug. 18–24	Subway	81.2	55.8	87.8	84.5	68.0	35.0
	Surface	76.9	59.5	90.0	83.0	65.0	34.5
	Difference	4.3	.7				
Aug. 25–31	Subway	79.5	57.1	88.5	94.0	67.2	30.0
	Surface	72.0	62.7	81.9	100.0	63.0	33.5
	Difference	7.5	5.6				
Sept. 1–7	Subway	79.3	54.5	85.0	84.0	70.0	38.0
	Surface	71.8	61.4	77.5	92.0	66.2	39.0
	Difference	7.5	6.9				
Sept. 8–14	Subway	78.4	52.0	84.5	85.0	61.0	26.0
	Surface	66.5	59.0	79.5	88.5	52.8	21.5
	Difference	11.9	7.0				
Sept. 15–21	Subway	78.1	62.2	84.2	89.0	63.2	33.5
	Surface	70.2	73.9	76.5	99.0	60.5	43.0
	Difference	7.9	11.7				
Sept. 22–28	Subway	76.0	40.5	84.2	72.5	59.2	22.0
	Surface	66.0	45.0	81.2	74.2	47.8	28.0
	Difference	10.0	4.5				
Sept. 29–Oct. 5	Subway	78.0	52.6	83.8	79.0	68.8	38.0
	Surface	72.1	57.7	81.8	91.0	64.1	33.0
	Difference	5.9	5.1				
Oct. 6–12	Subway	74.4	42.6	82.2	62.0	59.0	24.0
	Surface	63.4	51.2	80.0	87.0	51.7	26.0
	Difference	11.0	8.6				

TABLE III — *Continued*

Date, 1905.	Place.	Average		Maximum		Minimum	
		Temperature.	Humidity.	Temperature.	Humidity.	Temperature.	Humidity.
Oct. 13–19	Subway	73.6	53.2	81.7	80.0	60.9	29.0
	Surface	63.0	61.6	76.8	93.0	45.8	31.5
	Difference	10.6	8.4				
Oct. 20–26	Subway	67.3	44.2	79.0	90.0	49.9	23.0
	Surface	53.7	59.5	69.1	96.5	42.2	28.0
	Difference	13.6	15.3				
Oct. 27–Nov. 2	Subway	65.6	42.3	74.1	76.5	48.8	21.0
	Surface	49.4	56.0	59.0	90.0	38.9	28.5
	Difference	16.2	13.7				
Nov. 3–9	Subway	64.6	42.5	73.0	77.0	50.8	26.0
	Surface	50.1	58.9	58.5	88.0	41.5	33.0
	Difference	14.5	16.4				
Nov. 10–16	Subway	60.8	34.6	71.0	63.0	41.8	15.0
	Surface	42.3	51.2	58.0	86.0	24.0	10.0
	Difference	18.5	16.6				

The lowest temperature recorded at Canal Street up to January 1 was 30°. The outside temperature at the same time was 14°, giving a difference of 16°. At the same time, the temperature at the Brooklyn Bridge and Astor Place stations was 54°. Or, in other words, the Brooklyn Bridge station was 40° warmer than the outside air, while the Canal Street station was but 16° warmer.

The express stations, with the exception of 96th Street, which was exceptionally open to the outside atmosphere, were all warmer than the local stations in their vicinity.

The coolest stations were those which were most open to the street; the hottest the most closed.

Figure 6 shows variations of temperature at some stations recorded by the thermographs.

Humidity

The relative humidity in the subway was generally less than that out of doors, but the temperature of the dew point was higher. This is shown in Figure 7. In other words, the actual weight of aqueous vapor present was greater in the subway than outside, but it appeared to be less in the subway than in the streets.

The humidity in the subway varied with the humidity out of doors (see Fig. 8).

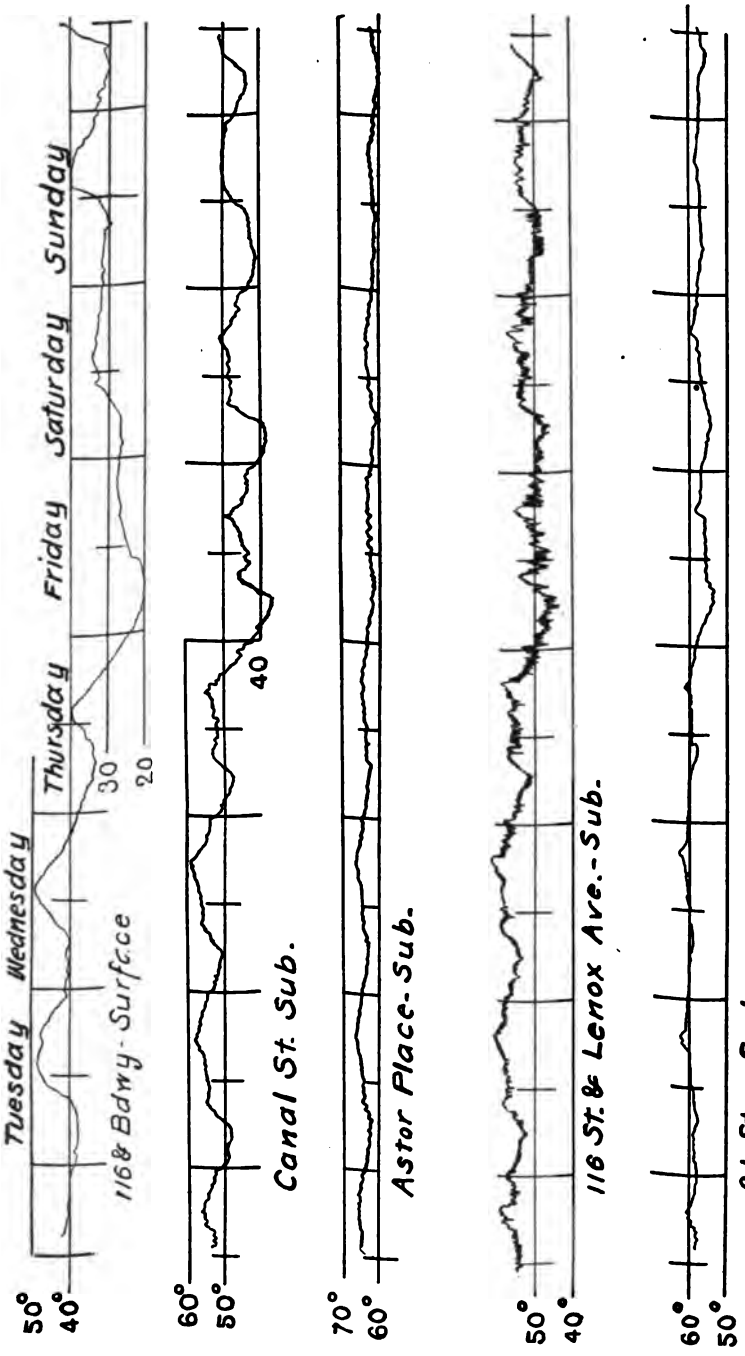

FIG. 6.—SYNCHRONOUS VARIATIONS IN TEMPERATURE AT DIFFERENT SUBWAY STATIONS AND IN THE STREETS, FOR ONE WEEK, AS SHOWN BY THERMOGRAPHS

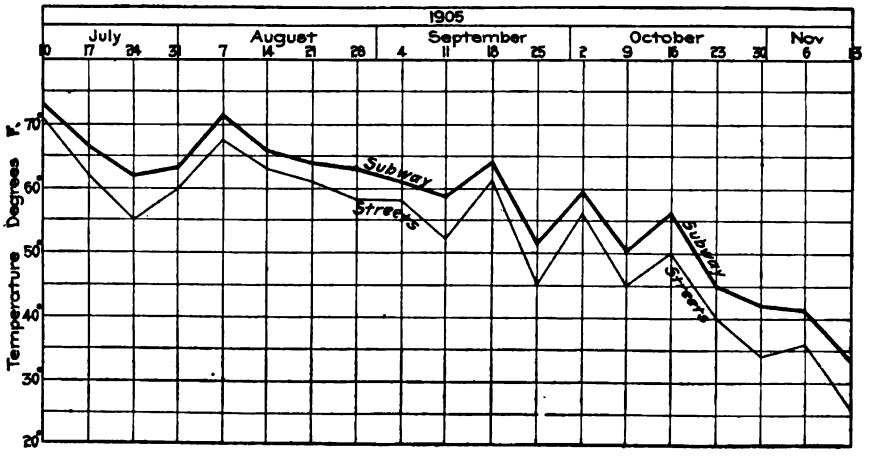

FIG. 7.—WEEKLY AVERAGE TEMPERATURE OF THE DEW POINT IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905

There were no fogs nor mists in the subway. A faint haze was not uncommon.

The average relative humidity for the subway for July and August was 57.5 per cent.; for the outside air, 60.6 per cent.; difference, 3.1 per cent.

The greatest average relative humidity occurred during the week when the average temperature was highest. During this period the relative humidity averaged 64.4 per cent.

Condensed records of humidity are given in Table III.

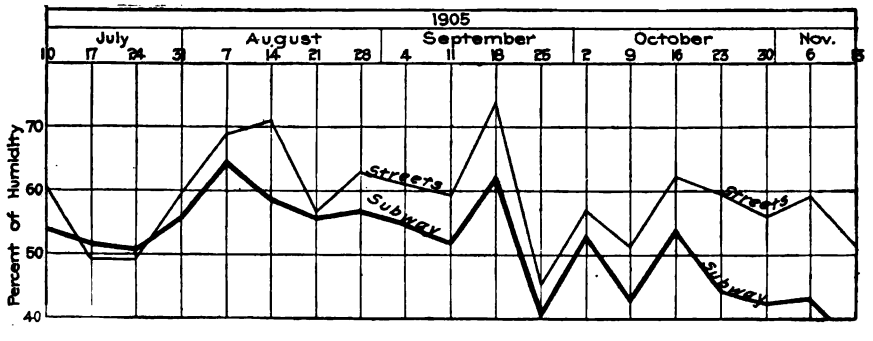

FIG. 8.—WEEKLY AVERAGE RELATIVE HUMIDITY IN THE SUBWAY AND STREETS FROM JULY 10 TO NOVEMBER 13, 1905. THESE AVERAGES ARE MADE UP OF 47,456 OBSERVATIONS

CHEMICAL CONDITION OF THE AIR

The chemical analyses of air were confined chiefly to determinations of carbon dioxide, for it was thought that no other test could give such a correct knowledge of the extent to which the air was vitiated by respiration, and none could be made on such a large scale as was wanted with so little probability of error.

METHODS OF ANALYSES

Analyses for Carbon Dioxide.—The samples of air for analysis for carbon dioxide were collected in large, round-bottom flasks, varying in capacity from 2,000 c.c. to 2,600 c.c., made especially for the purpose.

Experiments proved that titrations could be made much more accurately in round-bottom flasks than in the Erlenmeyer flasks usually employed, since the faintest pink color could readily be detected by giving the flask a rotary motion and observing the color through the depth of the liquid as it spread in a thin film upon the sides of the flask.

Each flask was provided with a well-fitting, two-hole rubber stopper, fitted with glass plugs. Before being used, the flasks were boiled with sulphuric acid to remove any free alkali which may have been present, and then carefully rinsed and standardized.

Six of these flasks were fitted into a basket, which was carried by the collector. A large football pump, with the valve reversed, to pump air from the flasks, was employed; and this, with about 10 feet of rubber tubing, a thermometer, and a notebook, completed the collector's outfit. This apparatus is shown in Figure 9.

When it was desired to collect a sample, the basket was opened and the stopper removed from one of the flasks. The free end of the rubber tubing was then inserted into the flask as far as the bottom. This done, the operator removed to a distance with his pump and pumped air from the flask for about four minutes. This amount of pumping was capable of removing about eight times the volume of air in the flask, and provided for the collection of a proper sample.

After the sample was collected, the stopper was replaced in the flask, the temperature noted, and the data observed which were to fix the identity of the sample.

The samples were usually analyzed on the day of collection or the day after. Experiments showed that no appreciable change took place by allowing a sample to stand for twenty-four hours before analyzing.

On its arrival at the laboratory, the flask was placed in an upright position on a suitable rest and one of the glass rods removed from the stopper. The stopper was then gently pressed down until it reached a point marked on the neck of the flask at which its capacity had been calibrated.

A pipette was next inserted through the hole in the stopper and 20 c.c. of standard barium hydroxide, to absorb the CO_2, allowed to flow

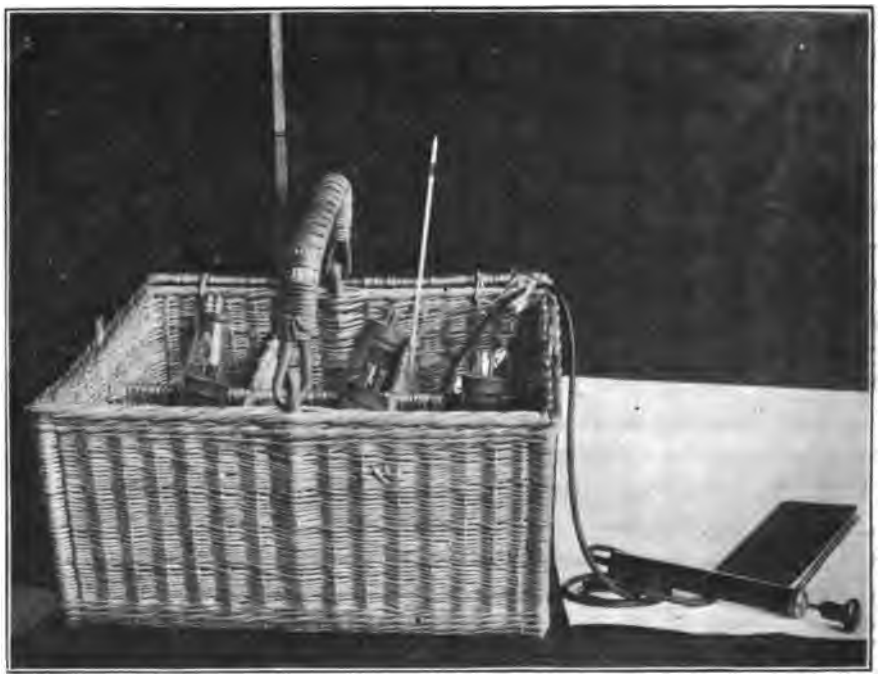

FIG. 9.—APPARATUS USED FOR COLLECTING SAMPLES OF AIR FOR CARBON DIOXIDE ANALYSES

into the flask with a few drops of plenolphthalein. The solution was allowed to stand, with occasional shaking, for one hour.

The delivery tube of a special burette was then inserted into the flask through one of the holes in the stopper, and the excess of barium hydroxide titrated with standard oxalic acid. The glass rod in the second hole of the stopper was removed from time to time to relieve the pressure. One cubic centimeter of this oxalic acid was equivalent to one-tenth of a cubic centimeter of carbon dioxide. From the quantity of barium hydroxide used, the amount of carbon dioxide in the original

sample of air was calculated, the volume being reduced to 0° C. and 760 mm. pressure.

Although the barium hydroxide solution remained practically constant from day to day, it was always standardized before each series of analyses.

The oxalic acid employed for making up the standard solution was tested by titrating with standard potassium permanganate and found to be satisfactorily pure.

The bottle in which the standard solution of barium hydroxide was kept was provided with a safety bottle containing pumice and caustic soda and a rubber bulb, which allowed the liquid to be forced up into the pipette instead of filling the latter by suction.

The burette used for titration was especially made for the purpose, and had a delivery tube 9 cm. long, which in use projected well into the flask of air.

Inasmuch as the manner in which the sample was collected gave room for some error if the collector was inattentive or careless in his work, care was taken to collect check samples from time to time by the help of other assistants. This error was further guarded against by entrusting the collections only to persons who, by age and training, seemed certain to use proper care. One of the collectors held the rank of assistant engineer under the Municipal Civil Service Commission of the city. Another was an analytical chemist of long experience.

A sample of air which was taken to check the work of a collector gave the following results:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Collector's sample	3.54
Samples collected as a check	3.48
Difference	.06

Experiments were made to determine whether or not long standing of the barium hydroxide solution in contact with the flask would have any effect on the results. For this purpose four samples of outside air were collected at the same time and place, and the barium hydroxide solution allowed to remain in the flask for periods of from one to four hours. The results follow:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Titrated at the end of one hour	3.48
Titrated at the end of two hours	3.47
Titrated at the end of three hours	3.49
Titrated at the end of four hours	3.48

Experiments to ascertain whether or not any difference in the results would be obtained by adding the barium hydroxide to the flask at the time of collection gave results which follow:

Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
Solution added at time of collection	4.33
Added four hours after collection	4.36

Another set of samples was taken and analyzed as follows:

No.	Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
1	Added barium hydroxide solution at time of collection	2.09
2	Added barium hydroxide solution at time of collection	3.02
3	Added barium hydroxide solution after eighteen hours	3.02
4	Added barium hydroxide solution after eighteen hours	3.11
5	Added barium hydroxide solution after eighteen hours (paraffined stopper)	3.13
6	Added barium hydroxide solution after eighteen hours (paraffined stopper)	3.22

Another set of samples was analyzed as follows:

No.	Conditions of experiment.	Parts CO_2 per 10,000 volumes of air.
1	Added barium hydroxide at time of collection	3.40
2	Added barium hydroxide at time of collection	3.56
3	Added barium hydroxide after twenty-four hours	3.44
4	Added barium hydroxide after twenty-four hours	3.57

Figure 10 shows the apparatus used for the absorption of carbon dioxide by barium hydroxide.

Analyses for Oxygen.—About eighty samples of air were analyzed for oxygen. The difference between the amount present in the subway and in the streets seemed so slight and uninstructive that the determinations were soon discontinued as a routine procedure.

FIG. 10.—APPARATUS USED FOR THE ABSORPTION OF CARBON DIOXIDE BY BARIUM HYDROXIDE IN THE CARBON DIOXIDE ANALYSES

The samples of air were collected in glass tubes of 300 c.c. capacity, closed at each end by glass stopcocks. The tubes were filled with oxygen-free water at the laboratory and taken to the point where the samples were to be collected. There the cocks were opened and the water allowed

to flow out, the desired sample of air taking its place. The cocks were then closed and the sample taken to the laboratory for analysis.

The oxygen was determined by absorption with phosphorus, according to the method of Lindemann. Hempel burettes and a Hempel pipette, constructed for solid absorbents, were employed. The phosphorus was specially prepared, and the pipette was kept covered to protect it from the action of light. The pipette, when in use, was immersed in water to maintain a constant temperature, and thus obviate any inaccuracy which might have been caused by temperature changes.

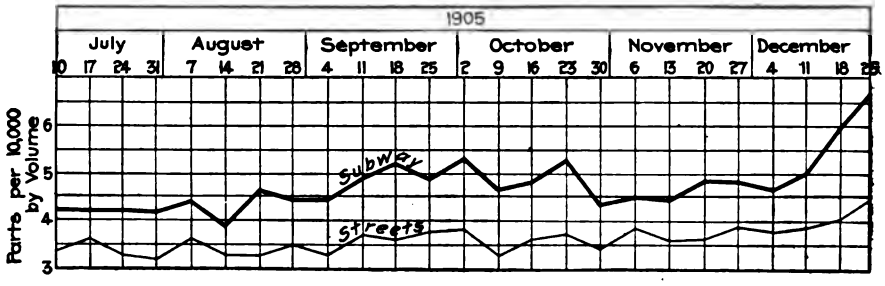

FIG. 11.—WEEKLY AVERAGE CARBON DIOXIDE FOR THE SUBWAY AND STREETS FROM JULY 10 TO DECEMBER 25, 1905, INCLUDING 1,772 DETERMINATIONS

CARBON DIOXIDE RESULTS

The carbon dioxide analyses produced results from which I derived the following conclusions:

The average amount of carbon dioxide in the subway was a little larger than in the air of the streets.

The average of all results was, for the subway, 4.81 volumes per 10,000 volumes of air, and for the streets, 3.67; difference, 1.14. This difference must be regarded as very slight (see Fig. 11).

The frequency with which the air was renewed could not be accurately calculated, for the reason that the number of passengers traveling in the subway was not known.

At no time or place was the amount of carbon dioxide large.

The greatest amount of carbon dioxide found in the subway was 8.89. This occurred in the tunnel between the Grand Central station and the 33d Street station, on December 27, 1905, at 6.02 P.M. At the same time there was a block, during which trains were stalled at all points in the vicinity. At the adjoining stations of 33d Street and Grand Central, the carbon dioxide was higher than usual at the same time, the amount at 33d Street being 7.84 and at Grand Central 7.87.

The carbon dioxide in the subway varied according to season, hour, place where the sample was collected, and other circumstances.

Season.—There was more carbon dioxide found in the autumn than

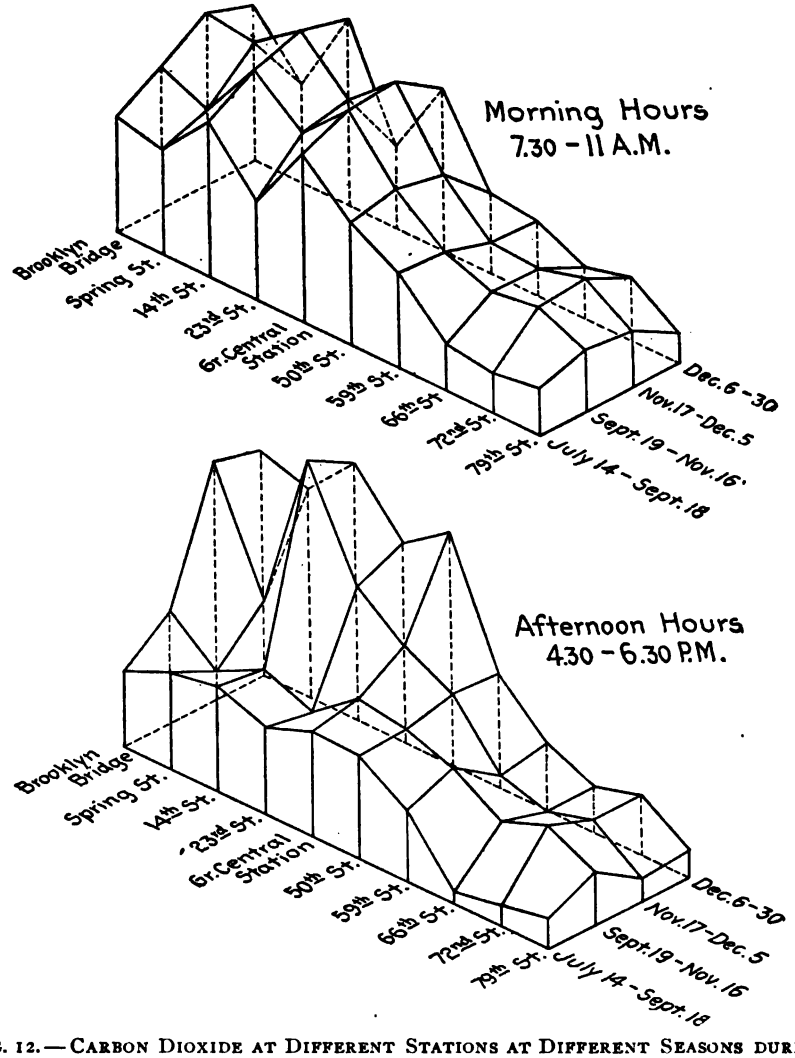

FIG. 12.—CARBON DIOXIDE AT DIFFERENT STATIONS AT DIFFERENT SEASONS DURING THE HOURS OF MAXIMUM TRAVEL IN THE MORNING AND AFTERNOON

in the summer or winter (see Fig. 12). It seemed likely that this was explainable largely on the ground that many more passengers were carried in autumn than in summer, and that in winter there was more wind in the streets and the subway, increasing the amount of ventilation.

Hourly Variations.—The amount of carbon dioxide varied in the subway at different hours of the day (see Fig. 13). These irregularities corresponded with the irregularities in the amount of travel which took place at different hours.

It is interesting to note that periodic changes in the amount of carbon dioxide occurred in the streets. In the streets the carbon dioxide was highest between 5.30 and 6 P.M., and lowest between 1 and 3 A.M. The amount increased from a minimum in the early morning hours to about 9 A.M. After this there was a fall to about 1.30 P.M., followed by a rise to the highest point of the day, which occurred between 5.30 and 6 P.M.

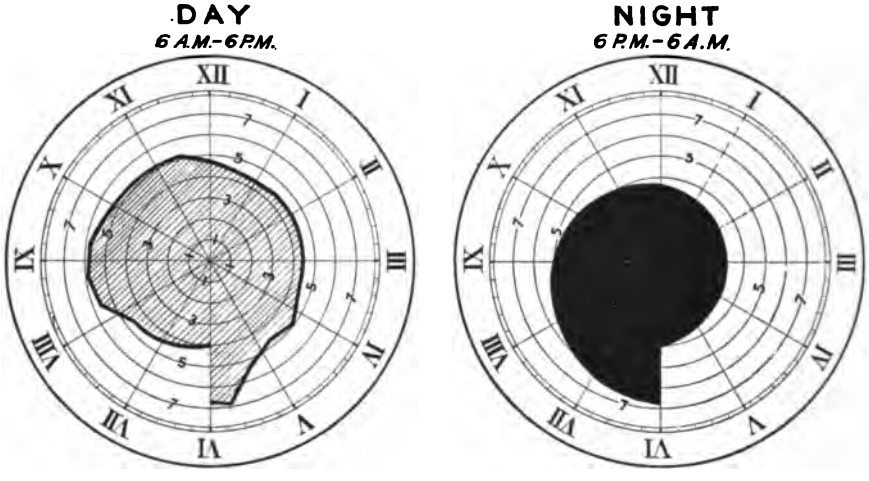

FIG. 13.—HOURLY VARIATIONS IN THE AMOUNT OF CARBON DIOXIDE IN THE AIR OF THE SUBWAY—AVERAGE OF 1,244 ANALYSES

The average range of CO_2 outside, as determined by hourly results, was .8 part per 10,000.

In the subway the greatest amount of carbon dioxide for the whole day also occurred between 5.30 and 6 P.M. Thereafter, there was a gradual fall to the lowest point, which was reached between 3 and 4 A.M.

From this lowest point the amount increased steadily to about 9 A.M., after which it fell irregularly to between 1 and 2 P.M.

The average for the whole day agreed closely with the average between 1 and 3 P.M.

In the late afternoon there was a rapid rise to the maximum for the day, which was reached at about 5.30 P.M.

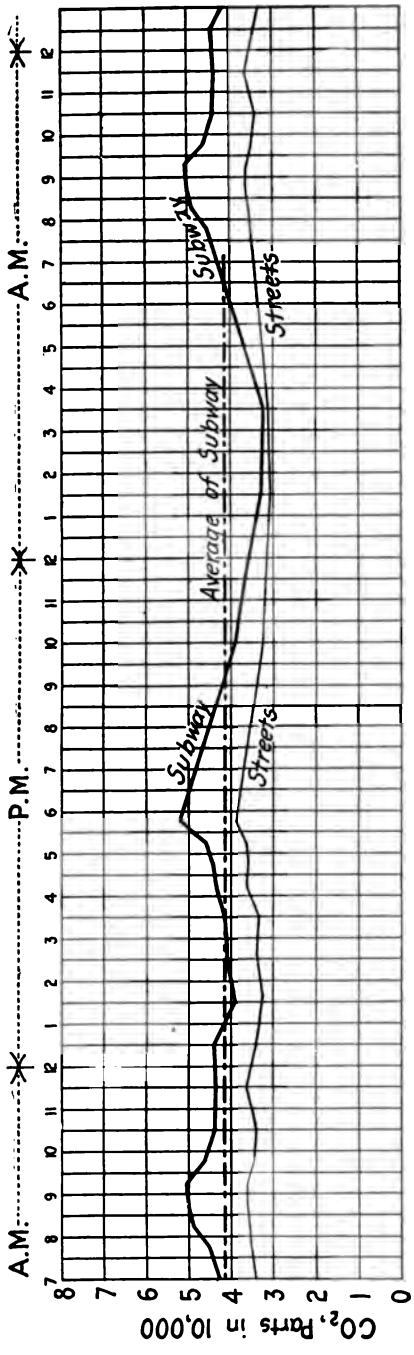

FIG. 14.—VARIATION IN THE AMOUNT OF CARBON DIOXIDE IN THE SUBWAY AND STREETS AS DETERMINED BY HOURLY ANALYSES—AVERAGE OF 1,510 ANALYSES

TABLE IV

SIMULTANEOUS DETERMINATIONS OF CARBON DIOXIDE AT AND BETWEEN STATIONS IN THE SUBWAY. THE NUMBER OF ANALYSES INCLUDED IN THIS TABLE IS 442

Date, 1905.	Point of observation.	Carbon Dioxide.	
		Found.	Excess.
July 31–August 4	Between Fulton Street and Brooklyn Bridge stations	4.26	
	Average for Fulton Street and Brooklyn Bridge stations	4.07	.19
	Between Brooklyn Bridge and Worth Street stations	4.35	
	Average for Brooklyn Bridge and Worth Street stations	4.37	—.02
	Between Worth Street and Canal Street stations	4.13	
	Average for Worth Street and Canal Street stations	4.29	—.16
	Between Canal Street and Spring Street stations	4.18	
	Average for Canal Street and Spring Street stations	4.47	—.29
	Between Spring Street and Bleecker Street stations	4.28	
	Average for Spring Street and Bleecker Street stations	4.40	—.12
	Between Bleecker Street and Astor Place stations	4.57	
	Average for Bleecker Street and Astor Place stations	4.61	—.04
July 29–August 5	Between Astor Place and 14th Street stations	4.68	
	Average for Astor Place and 14th Street stations	4.77	—.09
	Between 14th Street and 18th Street stations	4.46	
	Average for 14th Street and 18th Street stations	4.57	—.11
	Between 18th Street and 23d Street stations	4.17	
	Average for 18th Street and 23d Street stations	4.27	—.10
July 28–August 2	Between 28th Street and 33d Street stations	4.12	
	Average for 28th Street and 33d Street stations	3.99	.13
	Between 33d Street and Grand Central stations	4.48	
	Average for 33d Street and Grand Central stations	4.23	.25
July 28–August 1	Between Grand Central and Times Square stations	4.73	
	Average for Grand Central and Times Square stations	4.46	.27
	Between Times Square and 50th Street stations	4.44	
	Average for Times Square and 50th Street stations	4.27	.17
	Between 50th Street and 59th Street stations	4.07	
	Average for 50th Street and 59th Street stations	3.99	.08
December 14–23	Between Fulton Street and Brooklyn Bridge stations	6.31	
	Average for Fulton Street and Brooklyn Bridge stations	6.21	.10
December 14–26	Between Canal Street and Spring Street stations	6.06	
	Average for Canal Street and Spring Street stations	5.92	.14
December 15–22	Between 14th Street and 18th Street stations	6.74	
	Average for 14th Street and 18th Street stations	6.55	.19
December 26–27	Between 33d Street and Grand Central stations	7.21	
	Average for 33d Street and Grand Central stations	6.82	.39
December 15–22	Between Grand Central and Times Square stations	6.55	
	Average for Grand Central and Times Square stations	6.21	.34
December 13–21	Between 66th Street and 72d Street stations	4.78	
	Average for 66th Street and 72d Street stations	4.75	.03
December 28	Under Central Park, south of 110th Street station	6.18	
	At 110th Street station	5.45	.73
December 29	Under Harlem River	6.30	
	Mott Avenue station	4.58	1.72
Mean CO_2 between stations		5.05	
Mean CO_2 at stations		4.87	.18

The difference between the least and greatest amounts of carbon dioxide was, according to these hourly averages, two parts per 10,000.

Figure 14 shows the variation in the amount of CO_2 in the subway and streets as determined by hourly results.

Differences in Different Parts of the Subway.—There was more carbon dioxide at express stations than at local stations, except at the especially open express station at 96th Street.

Among the principal express stations, the largest average amount of carbon dioxide was found at 14th Street. Then came the Brooklyn Bridge, Grand Central, 72d Street, and 96th Street stations, in the order named.

There was more carbon dioxide between stations than at the adjoining stations, although in most cases this difference was very little. The results of 442 analyses showed this average difference to have been .18 parts per 10,000, with a range of from .29 to 1.72. Data relating to this subject are given in Table IV.

Marked differences occurred in the amount of carbon dioxide found at points above and below 50th Street. The average of all results which were capable of being taken into account to show this difference demonstrated that the air from 50th Street uptown was much purer than the air from 50th Street downtown. This is shown in Table V.

TABLE V

CARBON DIOXIDE IN THE SUBWAY NORTH AND SOUTH OF FIFTIETH STREET THE NUMBER OF ANALYSES INCLUDED IN THIS TABLE IS 1,182

FROM FIFTIETH STREET DOWNTOWN					
1905.	Brooklyn Bridge.	Spring Street.	Fourteenth Street.	Twenty-third Street.	Grand Central.
July 14–September 18	1.14	1.08	1.39	0.97	1.46
September 19–November 16	1.34	1.03	1.50	1.17	1.61
November 17–December 5	2.17	1.51	2.58	1.77	1.91
December 6–December 30	2.01	1.62	2.37	1.38	2.08
	1.66	1.31	1.96	1.32	1.76

TABLE V — *Continued*

FROM FIFTIETH STREET UPTOWN

	Fiftieth Street.	Fifty-ninth Street.	Sixty-sixth Street.	Seventy-second Street.	Seventy-ninth Street.
July 14–September 18	1.20	.88	.31	.32	.42
September 19–November 16	1.26	.97	.71	.86	.61
November 17–December 5	2.27	.71	.63	.82	.42
December 6–December 30	1.02	.75	.52	.65	.30
	1.44	.83	.54	.66	.44

Differences in the elevation above the pavement at which samples were taken made little difference in the amount of CO_2 found in the subway. These differences are indicated in Table VI.

TABLE VI

CARBON DIOXIDE AT DIFFERENT ELEVATIONS ABOVE THE PLATFORMS OF SUBWAY STATIONS

Date, 1905.	Place.	Time.	Two feet.	Four feet.	Six feet.	Eight feet.	Ten feet.	Average.
August 17	14th Street station . . .	2.00– 2.15^P	4.01	3.48	4.11	4.24	. .	4.05
August 18	Grand Central station .	9.45–10.10^A	5.35	4.83	4.73	4.71	4.73	4.87
	Brooklyn Bridge station	1.40– 2.15^P	4.21	4.41	4.36	4.18	4.18	4.27
August 19	Grand Central station .	9.35–10.00^A	4.84	4.61	4.59	4.69	4.71	4.69
August 22	14th Street station . . .	10.45–11.10^A	4.72	4.97	4.69	4.90	4.60	4.78
August 23	Grand Central station .	10.00–10.30^A	4.63	4.67	4.74	4.59	4.65	4.66
August 24	Brooklyn Bridge station	9.55–10.25^A	4.91	4.92	4.64	4.50	4.74	4.74
Mean CO_2 at different heights			4.67	4.61	4.55	4.54	4.60	4.58
Mean of all observations			4.58	4.58	4.58	4.58	4.58	4.58
Departure of mean for each height from mean of all observations			+.09	+.03	−.03	−.04	+.02	. .

The CO_2 in the air of the cars in summer, when the windows and front doors were open and the travel comparatively light, was not far different from the air of the subway itself.

OXYGEN RESULTS

The samples of air which were analyzed for oxygen were collected from 9.30 A.M. to 5.30 P.M., between the Brooklyn Bridge and 96th Street stations.

The average amount of oxygen found in the air of the streets was 20.71 per cent.; in the subway, 20.60 per cent.; difference, .11 per cent. The least amount found in the subway was 20.25 per cent.

BACTERIAL CONDITION OF THE AIR

The studies concerning the micro-organisms in the subway related chiefly to the number and origin of the bacteria and molds. It was not practicable within the time and scope of the investigation to determine the various species of bacteria present, but the principal sources of many of them were investigated indirectly with fairly satisfactory results.

Quantitative Methods of Analysis

The bacteria were collected by allowing them to settle from the air on circular plates, or Petri dishes, 3½ inches, or about 9 cm., in diameter, containing a standard agar culture medium, and by collecting them from the air by means of sand filters.

The Plate Method.—The plates containing the culture medium were carried from the laboratory to the points of observation in a handbag. The plates and covers were fastened together by means of elastic bands, each pair separated from other pairs by sterilized towels.

To make an observation, the plates were taken from the handbag and placed, usually, upon a bench about 18 inches from the pavement. The covers were then removed and kept off for fifteen minutes, or a fraction of this time, depending upon the observer's judgment of the numbers which would probably be found.

During the exposure of the plates, the observer removed to a distance and made the notes necessary to identify the observation.

The covers were then replaced, secured to their respective dishes by the rubber bands, and returned to the laboratory in the handbag. The plates were put into the incubator within two hours after exposure.

The plates were incubated at a temperature of 37° C. for forty-eight hours. The colonies of bacteria and molds which developed in this time were then counted. Care was taken to separate the two.

Most of the exposures were made at the subway stations at points as far removed from draughts as possible. Exposures out of doors were made, for the most part, on the line of the subway beyond the influence of subway air, and at an elevation of about 3 feet above the sidewalk.

In all, about 2,800 exposures were made.

The agar culture medium was prepared with Liebig's extract of beef and 5 per cent. agar.

The reaction of the medium, after preliminary trials to ascertain the

FIG. 15.—COLONIES OF BACTERIA GROWN ON A PLATE EXPOSED FOR FIFTEEN MINUTES AT THE GRAND CENTRAL SUBWAY STATION

optimum, was fixed at ½ to 1 per cent. acid to phenolphthalein. In preparing the plates for use, 10 c.c. of the agar medium was poured, and the plates then put into the incubator for twenty-four hours. Plates which developed colonies in this time were contaminated and not used.

All the bacteriological plates were exposed in duplicate. The results reported were averages of the counts of two plates in every instance.

Preliminary trials of different media and at different periods of incubation showed that a gelatin medium kept for several days at what is generally termed "room temperature" would often develop more colonies than an agar medium developed at body temperature. There

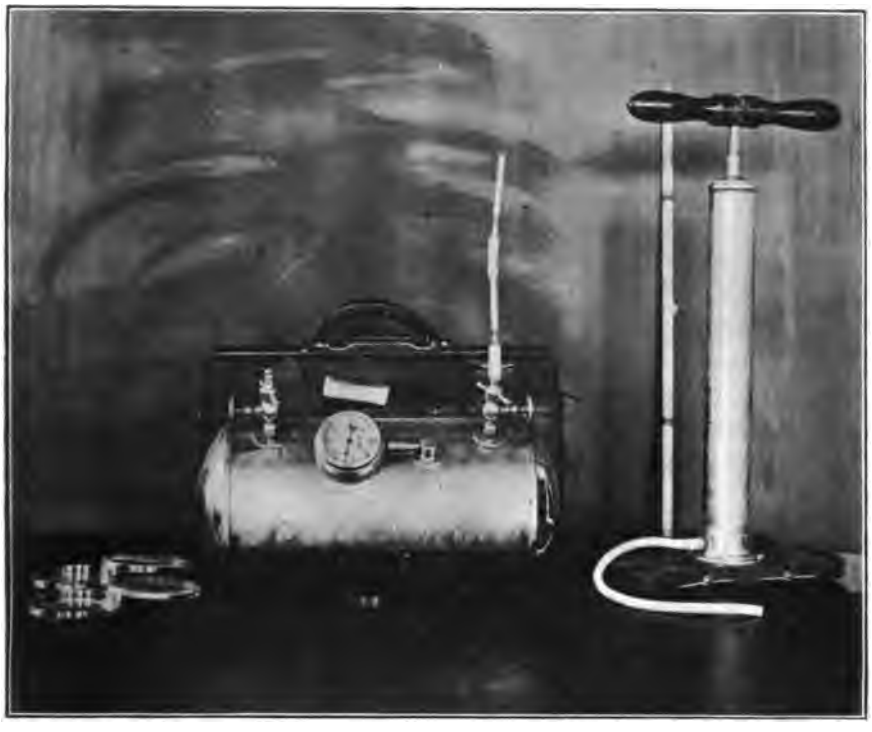

FIG. 16. — PORTABLE APPARATUS USED FOR ESTIMATING THE NUMBERS OF MICRO-ORGANISMS IN A MEASURED VOLUME OF AIR

were probably several reasons for this: The higher temperature of the body undoubtedly kept many delicate air organisms from growing. Gelatin was a more favorable solidifying agent than agar. An incubation period of more than forty-eight hours seemed to be essential to the growth, to visible colonies, of some bacteria in artificial culture media.

The chief objection to the gelatin-room-temperature method was that gelatin melted at a temperature which made it unsuitable for summer use, became too easily liquefied by certain bacteria, and was likely to be too rapidly overgrown with molds.

The procedure adopted seemed to be the most practicable under the circumstances. It had also the merit of being capable of duplication at any time and place with a considerable degree of accuracy.

The numbers of bacteria which actually existed in the air must have been largely in excess of the numbers found, but it was not feasible to ascertain how great was this difference.

Colonies of bacteria grown in a plate exposed for fifteen minutes to the air at the Grand Central subway station are shown in Figure 15.

The Filter Method.—The collection of micro-organisms by the use of filters provided means for estimating the numbers of bacteria and molds recoverable from a measured volume of air. After a considerable amount of preliminary work, the method adopted was substantially that employed by Sedgwick, Prudden, and others, and described in "Studies from the Department of Pathology, College of Physicians and Surgeons," New York, Volume VII, 1900 (see Fig. 16).

The filters consisted of glass tubes about 13 cm. long and 0.5 cm. inside diameter. At one end the filtering material was held in place by a small plug of wire gauze, and at the other, when the filter was not in use, by a plug of cotton.

Various filtering materials were tried in experiments preliminary to the adoption of a standard method, especially the sugar medium of Sedgwick, proposed before the Society of Arts in 1888 (see Sedgwick and Tucker, "Methods for the Biological Examination of Air," *Proceedings of the Society of Arts,* Boston, 1888). In the subway work the advantages of a soluble medium were apparently more than offset by the care with which the sugar required to be sterilized and kept dry.

The filtering medium finally adopted was sand. The depth of sand was about 5 cm. Most of the grains were about half a millimeter in diameter. The particles were largely quartz. Two filters were always arranged in tandem (see Fig. 17).

Air was made to pass through the filters, in most cases by means of an exhaust pump of accurate construction, whose action had been carefully tested. Sixty-six strokes pumped 20 liters, and this was the amount usually pumped in each case.

Where it was not feasible to use the air pump, a brass vacuum cylinder of about 600 cubic inches, or 10 liters, capacity, fitted with a pressure gauge and suitable stopcocks, was employed, as devised by Prudden. The cylinder was 266 cm. long and 177 cm. in diameter, and was fitted into a neat leather bag with suitable openings, through which the gauge could be read and the filters connected.

Before using the cylinder, the air was exhausted from it and the stopcocks closed. It was then placed in the handbag and taken to the place where the observation was to be made. The filters were then connected to the cylinder by means of short rubber tubing, the pressure

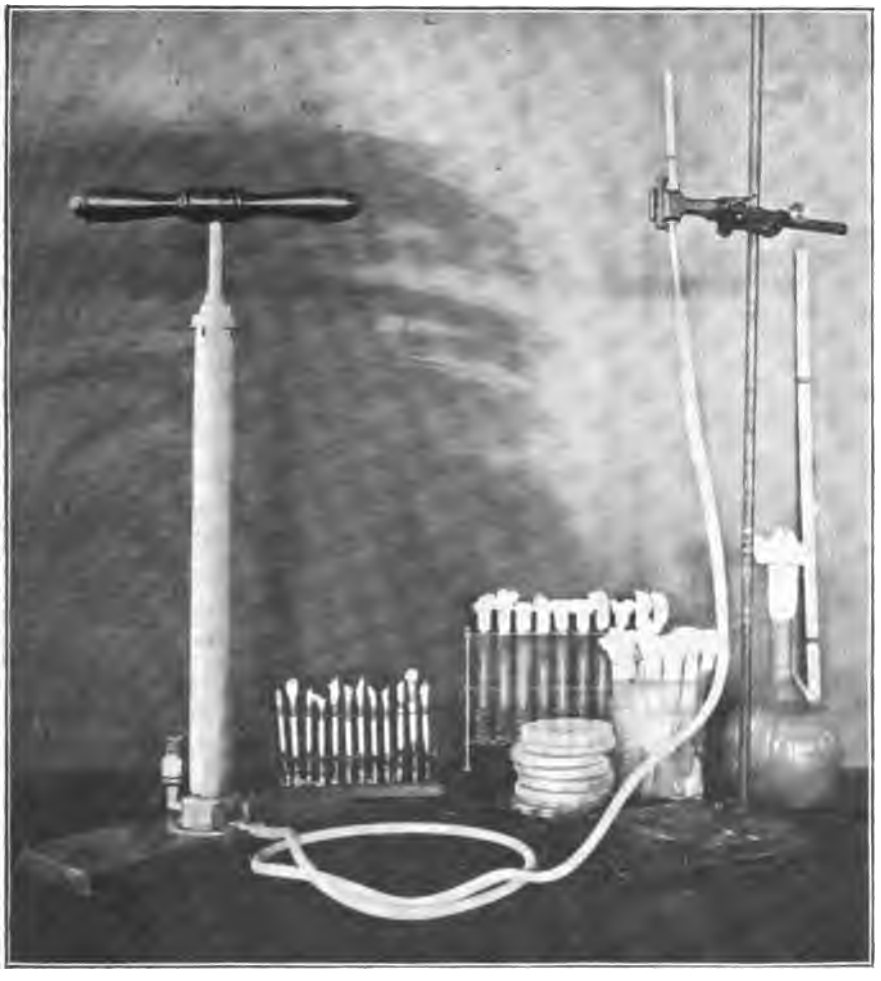

FIG. 17.—APPARATUS USED FOR ESTIMATING THE NUMBERS OF MICRO-ORGANISMS IN A MEASURED VOLUME OF AIR

gauge read, and the air allowed to flow into the cylinder through the filters. When the desired quantity of air had been filtered, the cocks were closed, the filters removed, and the gauge read.

Upon returning to the laboratory the sand was emptied from the

first filter into a test tube containing 10 c.c. of sterile water, and thoroughly agitated.

The water, with the organisms which had been rinsed from the sand, was then plated in agar and incubated for forty-eight hours at 37° C. and then counted.

The second filter was treated in the same way. Molds were excluded from the count.

Another method, and the one which was adopted finally, discarded the use of the distilled water. The sand from a filter was poured into a tube of melted agar, the tube agitated and then poured into a Petri dish, leaving the sand behind. A second tubeful of agar was then poured upon the sand remaining in the first tube. This was then agitated and the agar and sand both poured into a second Petri dish. The two Petri dishes were then incubated.

Most of the bacteria found were caught in the first filter.

Additional Bacterial Work

Beside the routine estimates of the number of bacteria recovered from the air, special studies were made of the length of life of the pneumococcus in the subway, the numbers of bacteria in subway and other dusts, the action of lubricating oil upon bacteria, the kinds of molds present, and the efficiency of various commercial deodorants and germicides intended for subway use.

The Longevity of the Pneumococcus.—The longevity of the pneumococcus was tested by drying upon a flat piece of broken trap rock about 20 c.c. of sputum from a patient suffering from lobar pneumonia in the congestive stage. The presence of the pneumococcus in a viable condition was tested in the beginning of the experiment and at the end of every two or three days. The vitality was determined by culture methods and by inoculating small portions of the moistened sputum into guinea pigs.

The rock with the dried sputum was taken into the subway and set upon the top of a clean iron beam at a little distance from the end of a station platform. Small parts of the mass were taken from day to day for examination, but the main body of sputum was not taken out of the subway until the end of the experiment.

The Numbers of Bacteria in Dusts.—Specimens of dust which had gathered upon recently painted beams and other clean, dry surfaces were

collected in large, sterile test tubes and Erlenmeyer flasks and taken to the laboratory. Here a small, weighed portion of the dust was mixed with from 50 to 500 c.c. sterile water. One cubic centimeter, and fractions thereof, of the water were then sown in the agar culture medium already described. The agar was incubated for forty-eight hours at 37° C. and counted. From these counts the numbers of bacteria per gram of dust were calculated.

Action of Oil on Bacteria.—The possibility that the lubricating oil which was copiously used in the first few months after opening the subway might have a germicidal or cultural effect upon bacteria was inquired into.

Specimens of oily wood, stone, and refuse paper from the tracks were taken to the laboratory and examined for the numbers of bacteria which they contained. The oil itself was tested for its action upon various species of bacteria.

Kinds of Molds.—Although it was not feasible to study the kinds of bacteria, because of the great similarity in their forms and cultural behavior, it was practicable to determine a few of the molds present. This was done by fishing from the mixed colonies of molds and bacteria which developed upon the plates exposed in the subway. From specimens obtained in this way, pure cultures were made upon various media suitable for the propagation of the molds.

No attempt was made to make this work exhaustive, since it seemed doubtful whether a complete knowledge of the numbers and kinds of molds in the subway, had it been obtainable, would have thrown much light upon the problems in hand.

Efficiency of Deodorants and Disinfectants.—The efficiency of different chemical compounds advocated by various persons to purify the air of the subway was examined into. They were tested both with reference to their capacity for destroying unpleasant odors and bacteria.

The capacity of these compounds to destroy odors was tested in the laboratory by producing unpleasant odors in suitable closed chambers, and then introducing the compound in different amounts and under different circumstances of temperature and humidity.

The disinfectant properties of the compounds were tested by allowing them to act upon bacteria in colonies on culture media, in films and emulsions, on toothpicks, and on freshly impregnated cotton threads. The germs used in these experiments were the typhoid bacillus and the colon bacillus, the pneumococcus and the Staphylococcus pyogenes albus.

The laboratory procedures were such as are usually employed in careful work of this kind.

Results

A careful examination of the bacterial data collected in these studies, excepting the data which relate to the dust, has led me to the following conclusions:

Numbers of Bacteria in Subway and Streets Compared.—There were, on an average, more than twice as many bacteria found in the air of the streets as in the air of the subway, excepting after rains, when fewer were found outside than inside.

The average numbers of bacteria which settled from the air in fifteen minutes, and were subsequently enumerated, were, in the subway, 500; outside, 1,157; difference, 657 (see Figs. 18 and 19).

The average number of bacteria found by filtering the air was 3,200 per cubic meter in the subway and 6,500 in the streets; difference, 3,300.

Molds.—The molds recovered from the air by filters were almost always less numerous in the subway than out of doors. The maximum number of molds found was 1,100 per cubic meter. This observation was made in the tunnel under Central Park.

The average ratio of molds to bacteria, as determined by the observations with filters, was 1 to 40 in the subway.

Effects of Wind in the Streets.—The wind in the streets had a decided effect upon the numbers of bacteria collected from the air, both inside and outside of the subway. The averages show that five times as many were recoverable from the air in the streets with a wind of 18 miles per hour as with a wind of 9 miles.

Origin of the Bacteria.—No attempt was made to identify the different kinds of bacteria. To have undertaken to name the species, even with a great deal more time than was available and a special corps of bacteriologists, would probably have produced little result. Nevertheless, the conclusion was reached that most of the bacteria in the subway come from the streets. The principal reasons for holding this view follow:

1. The numbers of bacteria recovered from the air of the subway varied with the more decided changes in the streets.

2. The bacteria were more numerous at the subway stations near the stairways than at the remote ends of the platforms.

3. In the subway stations, the bacteria were more numerous on that side of the road toward which the wind blew than on the opposite side.

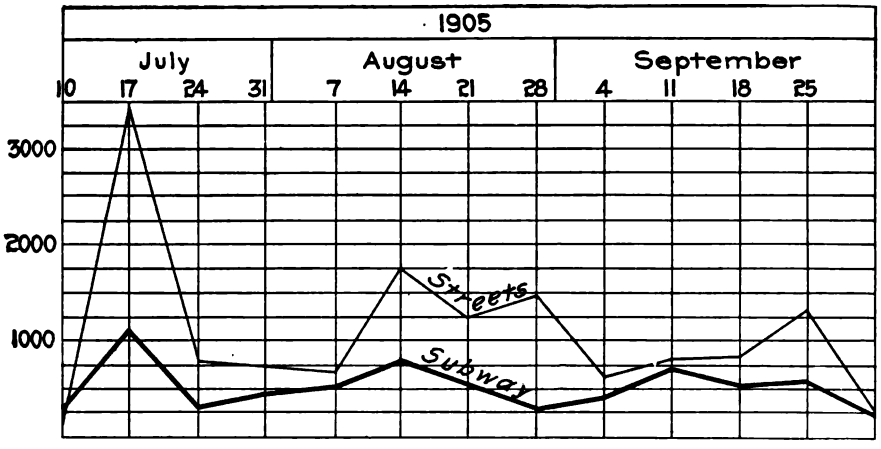

FIG. 18.—AVERAGE NUMBERS OF BACTERIA WHICH SUBSIDED FROM THE AIR PER SQUARE FOOT PER MINUTE, AS DETERMINED BY THE PLATE METHOD, IN THE SUBWAY AND STREETS FROM JULY 10 TO OCTOBER 2, 1905. THE NUMBER OF SAMPLES REPRESENTED IS 2,742

4. There were more bacteria at the arrival ends of the platforms of the stations than at the departure ends.

5. Street dirt, probably containing large numbers of bacteria, was often carried down the stairways into the subway by inrushing currents of air and by the passengers.

Although it seemed likely from these reasons that most of the bacteria in the air of the subway were derived from the streets, there was ground for concluding that some, and among them objectionable kinds, were due to the presence of the people. It is practically certain when great crowds are packed together, as they often were in some stations and most cars, that dangerous bacteria are, at least occasionally, transmitted

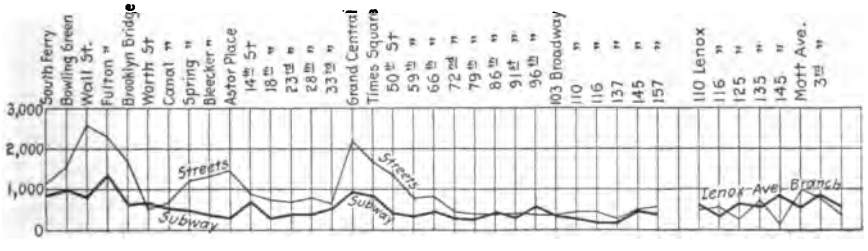

FIG. 19.—AVERAGE NUMBERS OF BACTERIA WHICH SETTLED FROM THE AIR UPON EACH SQUARE FOOT PER MINUTE AT DIFFERENT SUBWAY STATIONS AND IN THE STREETS. THE NUMBER OF SAMPLES REPRESENTED IS 2,753

from person to person. An obvious feature of this danger lies in the fact that people talk, cough, and sneeze into one another's faces at extremely short range under such circumstances.

Effect of Trains.—The numbers of bacteria in the air of the subway varied with the amount of travel. They were most numerous when the trains were most numerous, and fewest when the trains were fewest.

When the trains were blocked many of the bacteria disappeared from the air. In one case the bacteria were reduced from 1,800 to 250 in about an hour in this way. This is shown in Table VII.

TABLE VII

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY A BLOCKADE LASTING AN HOUR, NOVEMBER 11, 1905

Place.	Time.	Micro-organisms per Cubic Meter of Air.	
		Bacteria.	Molds.
110th Street and Broadway station, north end, east platform. Soon after the collection of the first sample all trains stopped running. Finally, no passengers in subway	10.20ᵃ	1,300	0
	10.37ᵃ	750	0
	10.55ᵃ	400	0
	11.15ᵃ	250	0
Average	. .	700	0

Effect of Sweeping.—The effect of sweeping the platforms with brooms, without first taking precautions against raising dust, was noted. On one occasion the numbers of bacteria were increased by sweeping from about 5,000 to 13,000, and remained above 8,000 for at least three-quarters of an hour—the time covered by the observation. The effect of sweeping is shown in Table VIII.

Effects on Harmful Micro-Organisms.—It was not found that any harmful germs were capable of multiplying in the oil which dripped from the machinery of the cars upon the broken stone ballast and wooden ties of the roadbed.

The lubricating oil apparently removed and collected from the air large numbers of bacteria, many of which soon ceased to exist.

The pneumococcus was found capable of retaining its virulence in dried sputum in the subway for twenty-three days. This is in marked contrast to the findings of Wood, who reported that the pneumococcus was killed in four hours in sunlight.

TABLE VIII

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY SWEEPING THE PLATFORMS IMPROPERLY

Place.	Time.	Micro-organisms per Cubic Meter of Air.		Ratio of bacteria to molds.
		Bacteria.	Molds.	
Fulton Street station, south end, west platform. Remote from openings to streets	10.25ᵃ	4,900	100	49 : 1
Porter began sweeping near by	10.41ᵃ	13,200	50	264 : 1
Still sweeping, but farther off	10.57ᵃ	8,100	0	. .
Still sweeping, middle of platform	11.12ᵃ	8,500	0	. .
Average	. .	8,600	38	226 : 1

With few exceptions, there were not so many bacteria in the air of the toilet rooms as in the rest of the subway. In some cases the numbers were much greater.

Inefficiency of Proprietary Disinfectants.—The proprietary disinfectants used in the toilet rooms had no germicidal or deodorizing value. Furthermore, they produced counter odors of a peculiarly unpleasant character.

Numbers of Micro-Organisms in Dusts.—The numbers of bacteria recovered from the dust of the subway averaged 500,000 per gram.

The largest number of bacteria found in subway dust was 2,000,000 per gram. Still greater numbers probably could have been found by selecting the specimens of dust toward this end.

For comparison with the numbers of bacteria found in dust from the subway, it is interesting to note that dust which had accumulated under similar circumstances in a Broadway theater contained 270,000 bacteria; in a new and fashionable hotel, 360,000; in a well-known Fifth Avenue church, 320,000; in the tallest office building in the city, 850,000; and in the attic of a country house one hundred and fifty years old, 110,000 bacteria per gram. The full results of these analyses are given in Table IX.

Dust which had accumulated in the subway contained over twice as many molds as dust collected in outside buildings. In the dusts the ratio of bacteria to molds was 89 to 1 for the subway, and 250 to 1 elsewhere.

TABLE IX

NUMBERS OF BACTERIA AND MOLDS FOUND IN ACCUMULATED DUSTS

Date, 1905.	Place.	Sample No.	Number Micro-organisms per Gram of Dust.		Ratio of bacteria to molds.
			Bacteria.	Molds.	
October 23	96th Street station	1	550,000	1,500	367 : 1.0
October 24	Grand Central station	2	1,000,000	2,500	400 : 1.0
October 25	14th Street station	3	2,000,000	500	4,000 : 1.0
October 26	Wall Street station	4	600,000	4,100	146 : 1.0
October 26	Brooklyn Bridge station	5	1,100,000	6,500	169 : 1.0
October 31	Columbia University station	6	81,000	1,600	51 : 1.0
November 1	Fulton Street station	7	1,000,000	3,500	286 : 1.0
November 2	South Ferry station	8	300,000	5,600	54 : 1.0
November 3	Times Square station	9	160,000	6,400	24 : 1.0
November 4	72d Street station	10	600,000	2,900	207 : 1.0
November 6	66th Street station	11	460,000	0	. . .
November 8	125th Street and Lenox Avenue station	12	650,000	6,500	100 : 1.0
November 9	Mott Avenue station	13	470,000	11,000	43 : 1.0
November 10	149th Street and Third Avenue station	14	440,000	8,700	51 : 1.0
November 11	110th Street and Broadway station	15	290,000	6,000	48 : 1.0
November 13	Columbus Circle station	16	190,000	1,100	173 : 1.0
November 14	23d Street station	17	160,000	2,300	70 : 1.0
November 15	Grand Central station	18	650,000	550	1,182 : 1.0
November 16	14th Street station	19	500,000	17,000	29 : 1.0
November 17	Brooklyn Bridge station	20	370,000	11,000	34 : 1.0
November 18	Wall Street station	21	270,000	12,000	23 : 1.0
November 20	50th Street station	22	150,000	11,000	14 : 1.0
November 21	South Ferry station	23	120,000	4,200	29 : 1.0
November 22	96th Street station	24	340,000	5,000	68 : 1.0
November 23	Brooklyn Bridge station	25	800,000	8,300	96 : 1.0
November 24	Times Square station	26	370,000	2,200	168 : 1.0
November 25	Grand Central station	27	650,000	2,300	283 : 1.0
November 27	14th Street station	28	300,000	14,500	21 : 1.0
December 5	South Ferry station	31	51,000	3,900	13 : 1.0
December 6	Canal Street station	34	230,000	6,500	37 : 1.0
December 4	Attic of house 150 years old, Hadley, Mass.	29	120,000	6,300	19 : 1.0
December 4	Attic of house 150 years old, Hadley, Mass.	32	110,000	5,600	20 : 1.0
December 4	Cellar of old Hadley house	33	52,000	120,000	1 : 2.3
December 7	A fashionable hotel	35	360,000	4,400	82 : 1.0
December 7	A Fifth Avenue church	36	320,000	5,800	35 : 1.0
December 8	A Broadway theatre	37	270,000	0	. . .
December 9	A downtown restaurant	38	1,200,000	0	. . .
December 9	Twentieth floor of an office building	39	850,000	1,500	567 : 1.0
December 9	Public ward of hospital	40	600,000	2,600	231 : 1.0
Average of thirty subway observations			500,000	5,600	89 : 1.0
Average of six New York buildings			600,000	2,400	250 : 1.0

ODORS

Odors were more or less prevalent at all times and at nearly all places in the subway. In some cases they were so faint as hardly to be noticeable, in others very decided.

The effects of the odors upon the passengers varied with the sensitiveness of the individual. To some persons the odors were exceedingly offensive, to others they were barely noticeable; many passengers soon became used to the odors and did not seriously object to them.

To persons unaccustomed to the subway the odors were unpleasant, and suggested that conditions existed which were injurious to health.

The odors were most apparent during hot, damp weather, at places where the greatest crowding occurred and where the least amount of ventilation took place.

Odors were far more often offensive in the cars than elsewhere, especially in the fall and winter months, when the windows were closed and the number of passengers was unusually large.

Methods of Investigation

An effort was made to ascertain the main causes of the odors. It was not possible to analyze them chemically or to measure them by other means than the senses, although samples of subway dust and air, when brought to the laboratory, often smelt unmistakably of the subway. By inspections in the subway and repair shops, by examining in the laboratory a large number of solid and liquid substances taken from the subway, and by attempting to duplicate the odors in closed chambers under different conditions of temperature and humidity, some of the causes of the odors were discovered.

Results of Investigating the Causes

The following conclusions are, in my view, justified by these studies:

Stone Ballast.—The stone ballast of the roadbed was responsible for part of the odor. This stone was made of broken trap rock, and its peculiarly slaty odor in the warm atmosphere of the subway was unmistakable. It could be most easily distinguished, especially at the more open stations, on damp days.

Frequently the odor of the trap was masked by other odors.

Lubricants.—The oil used in lubricating the wheels and machinery of the cars was one of the principal causes of odor. Large quantities of this oil were allowed to drip from the machinery upon the ballast and ties of the roadbed when the subway was first put in operation.

Samples of the oil were obtained for experiment. It was not feasible to determine by analysis its exact composition, but in other ways it was ascertained that it was composed chiefly of petroleum and fish oil.

The quantity of oil used in the subway in the first year of operation appeared larger than had ever been used on an equal length of road. It probably amounted to over 200 gallons per mile of road per month.

In addition to this oil, about 150 pounds of gear grease were used per mile per month.

Much of the oil and grease was heated on the bearings, and some of it was volatilized. The car journals, motor armature bearings, and motor axle bearings were sometimes raised to a temperature of from 100 to 170° F.

That the oil was distributed through the atmosphere of the subway was fully demonstrated. It was recovered from the dust by extraction with ether to the extent of 1.18 per cent. by weight.

Results of evaporation tests of the lubricating oil, according to the method of Gill, are given in the following tables:

LOSS IN WEIGHT OF SUBWAY OIL BY EVAPORATION — AIR TEMPERATURE

Sample No.	Per cent. loss after twenty-four hours at 25–29.9° C.
1	0.31
2	0.35
3	0.45
Average	0.37

LOSS IN WEIGHT OF SUBWAY OIL BY EVAPORATION — TEMPERATURE OF PARTS LUBRICATED

Sample No.	WHEEL JOURNALS.	AXLE BEARINGS.
	Per cent. loss after eight hours at 74–76° C.	Per cent. loss after eight hours at 110–115° C.
1	. .	6.93
2	1.57	8.04
3	1.08	7.65
4	1.86	7.77
5	1.86	9.22
Average	1.59	7.92

It will be noted that at air temperature there was a loss of 0.37 per cent., and 7.92 per cent. at 110° and 115° C. Under similar conditions whale oil, high grade fish and rape seed oils showed gains of from 1.01 to 5.39 per cent. at 74° and 76°, and losses of 0 to 2.65 per cent. at 110° and 115°, respectively.

Motors.—Odors were given off by the hot motors acting upon various more or less volatile substances other than oil and grease. Among these substances were the insulating material covering some of the electric wiring and the paint upon the motor cases.

Electric sparking produced the odors of ozone and nitrous oxide.

The hot brake shoes gave off a peculiar odor.

Disinfectants.—A pungent and unpleasant odor was produced by the proprietary disinfectants used in the toilet rooms. This odor was so penetrating that it was occasionally noticeable on the streets outside of the subway.

Tile Cement.—A strong and disagreeable odor was caused by an oily cement used in fastening decorative tiles in place at some of the stations. An ingredient of this cement was a cheap grade of fish oil. In order to disguise the fishy odor, creosote was freely mixed with the oil before mixing it with the cement. The result of these intermingled odors was peculiarly unpleasant. Fortunately, the odor of the cement, although very powerful at first, rapidly disappeared.

Hot Boxes.—Hot boxes, of which there were a considerable number when the road was first put in operation, at times produced a persistent and suffocating odor. Wool waste was used in packing the car journals, and when this caught fire its unpleasant smell could be distinguished through the subway for a long time.

Fuses.—Occasionally a fuse was blown out and its odor distributed up and down the line. When a fire occurred, as happened on a few occasions, the odor of smoke persisted in the part of the subway where the fire occurred for a surprisingly long period of time. In one case the odor was distinctly noticeable to passengers, as the cars passed the spot, three months after the fire had taken place.

Tobacco Smoke.—The odor of tobacco smoke was not uncommon at the subway stations. Rules existed against smoking in the subway, but they were not enforced. Lighted cigars, cigarettes, and pipes were occasionally carried even into the cars.

Concrete and Fresh Paint.—Odors from new concrete and fresh paint were often noticed. The former was persistent, the latter transient.

Odors of Human Origin.—Odors of human origin were sometimes present, but almost always close to people. They were most common during warm, damp weather and where there was much crowding. These odors often came from the clothing of the passengers. It was sometimes possible to learn the occupation of a workman by the odor of his clothes. Odors of coffee, garlic, bad teeth, liquor, cheese, and perfumery were some of the personal odors noticed.

The peculiar odor given off by clothing which had been hung in a kitchen was frequently noticed.

In fact, under the conditions of crowding, amounting frequently to close personal contact, it seemed that odors of practically every character connected with human existence were noticeable.

Excepting in rare instances, where ignorant employees were not kept under as strict supervision as their defective sense of decency required, the odors which permeated the general air of the subway did not point to conditions dangerous to health. Personal odors were detectible only at short range. When people are crowded so closely together that their breath and other body-odors are offensive, there is always danger that disease may be transmitted from one to another.

The toilet rooms were much neglected at the time of this investigation, and often gave rise to an unpleasant local odor.

DUST

The dust of the subway was made the subject of study because of its unpleasant features and the possibility that it might play a part in producing or aggravating respiratory diseases. Its possibilities for harm were to lie perhaps in its bacterial and physical composition.

Methods of Examination

The dust was examined microscopically, chemically, and bacteriologically, by a special method which was devised for determining the gross weight of dust in a measured volume of the air, and by an instrument for estimating the total number of floating particles present.

Microscopical and Chemical Examination.—The microscopical analyses were intended to show the shape of the particles and what could be ascertained in this way concerning their physical composition. The dust was examined under low powers of the microscope and with magnifications as high as 1,200 diameters.

It was possible, by means of a common horseshoe magnet held beneath a piece of paper sprinkled with the dust, and slowly moved from side to side, to distinguish particles of iron and steel. These metal particles could be made to rise on edge and reverse their position by changing the pole of the magnet presented to them.

The chemical analyses were intended to indicate the amount of iron, organic matter, silica, and oil.

Bacteriological Examination.—The bacteriological analyses were

intended to give some idea of the numbers of bacteria and molds present in dusts which collected at different points. The bacteriological method employed in this work has been already sufficiently explained.

Weight of Dust in Air.—At first the gross weight of dust in a measured volume of air was determined by means of a sugar filter, through which air was exhausted by means of an air pump. The amount

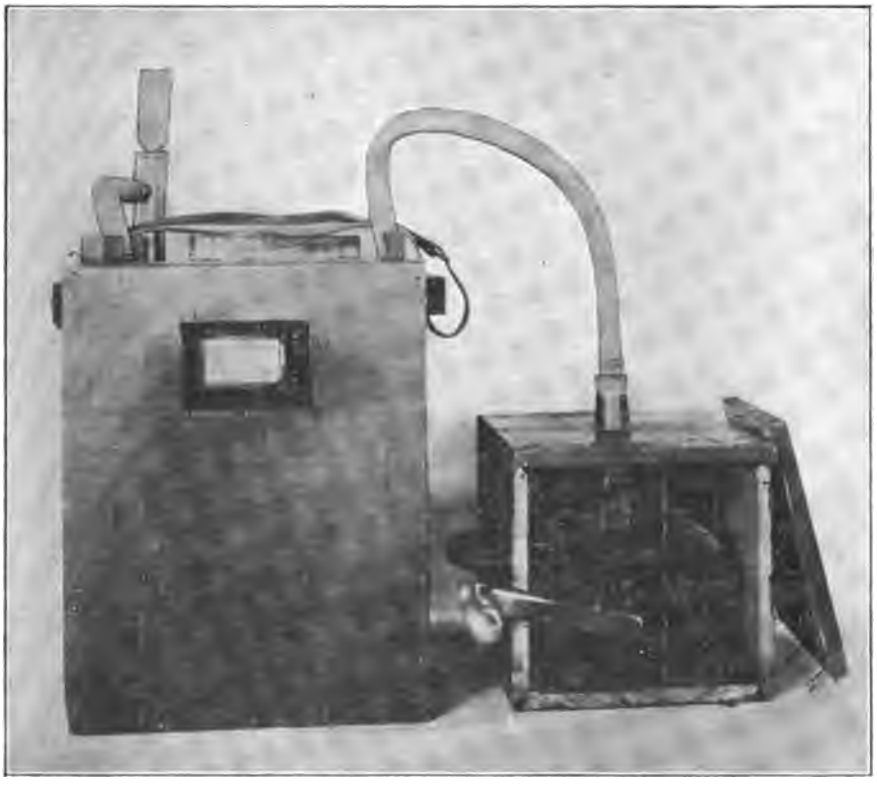

FIG. 20.—APPARATUS USED FOR ESTIMATING THE WEIGHT OF DUST IN A MEASURED VOLUME OF AIR

of air which it was desirable to pass through the filter proved to be too great for an air pump of ordinary capacity. After experimenting with nearly every pump and blower on the market which promised to serve the purpose, a small Root's blower was employed, the blower being operated, as an exhaust, by hand, by means of a crank. A test meter, manufactured by the American Meter Company, New York, was used to measure the air. The meter was examined and found to be accurate to within 1½ per cent. when used in this way.

The filter consisted of 10 c.c. of finely granulated sugar, contained in a glass funnel of 2.5 cm. diameter, with straight upper sides. The sugar rested upon a plug of wire gauze and was 5 cm. deep.

It was customary to pump 50 cubic feet, or 1,416 cubic meters, of air through a filter for each observation.

The apparatus was so connected that the air passed first through the filter, next through the meter, and finally through the Root's blower, which was, of course, run backward in order to obtain the exhaust. This apparatus is shown in Figure 20.

When the filter reached the laboratory, the sugar was carefully emptied into a beaker of distilled water. After the sugar was dissolved, the dust particles which remained were collected in a weighed Gooch filter containing a felt of asbestos. The filter was then washed with distilled water, dried at a temperature of 100° C., cooled, and again weighed. The increase in weight was taken to be the weight of the dust. From the data so obtained, the weight of dust in milligrams per cubic meter of air was calculated.

Ultimate Number of Dust Particles

The number of ultimate particles of dust was estimated by means of a koniscope, the invention of Professor John Aitken, F.R.S. A portable form of this instrument was imported from Glasgow for the purpose.

The koniscope has not been so much used in sanitary investigations as its merits deserve, and a few words of description may be desirable concerning it. It consists essentially of a brass tube closed at both ends by glass disks. Attached to the tube, near one end, is an air pump with suitable connections and stopcocks (see Fig. 3).

To estimate the number of particles of dust, the instrument was taken to the place where the atmosphere was to be examined. Air was pumped freely through the tube. The stopcock connecting the tube with the outside air was then closed. A rapid stroke of the pump made a partial vacuum in the tube, and this rarification produced a cloud or fog which could be distinctly seen by pointing the tube toward the light and looking through one of the glass disks at the ends. The dust particles served as nuclei about which the moisture condensed.

The depth, color, and intensity of the fog indicated the number of dust particles present. Professor Aitken has invented a more elegant and exact, but less portable, dust counter with which the koniscope can be

FIG. 21.—DUST COLLECTED ON A WHITE TILE EXPOSED AT THE 59TH STREET SUBWAY STATION FOR ONE WEEK

standardized. This more refined apparatus was tried in the subway, but without wholly satisfactory results. It was very delicate in respect to adjustment, and required a better light than was obtainable. The approximate number of particles was usually estimated with the koniscope from the appearance of the fog, and in accordance with the table kindly supplied by Professor Aitken.

Results

The studies of dusts led to the following conclusions:

Physical Character of the Dust.—In appearance, the dust was always black and very finely powdered. It was easily distinguishable by the eye from dusts collected in the streets, and in theaters, churches, office buildings, and mercantile and manufacturing establishments.

The subway dust had a peculiarly adhesive character, which caused it to attach itself securely to all surfaces, even when these were vertically placed and glazed. Dust collected on a white tile exposed at the 59th Street subway station is shown in Figure 21. All parts of the subway which had not been recently cleaned and painted, or were not of a dark color, were sprinkled with this black dust when the investigation began.

The dust had a marked capacity for soiling linen and other articles of clothing. Straw hats and the light-colored garments worn by passengers of both sexes in summer were likely to be soiled by coming in contact with even small accumulations of the dust.

When examined microscopically, the dust was found to be composed of particles of many substances, conspicuous among which were fine, flat plates of iron. In fact, these iron particles could often be seen with the naked eye, glistening upon the hats and garments of persons who had been riding in the subway.

Particles 2 mm. long were, on one occasion, taken from a magnet which had been carried in the hand on a ride of twenty minutes in the cars. By comparison, it was found that magnets hung up in the subway collected more particles of iron than magnets of the same size and strength hung up in an iron foundry or a dry grinding and polishing establishment. Figure 22 shows a magnetic field formed by subway dust.

The size, as well as the number, of the particles depended upon the place where they were found.

Many were so small that they floated in the air as dust. These generally escaped notice, except where beams of sunlight entered the

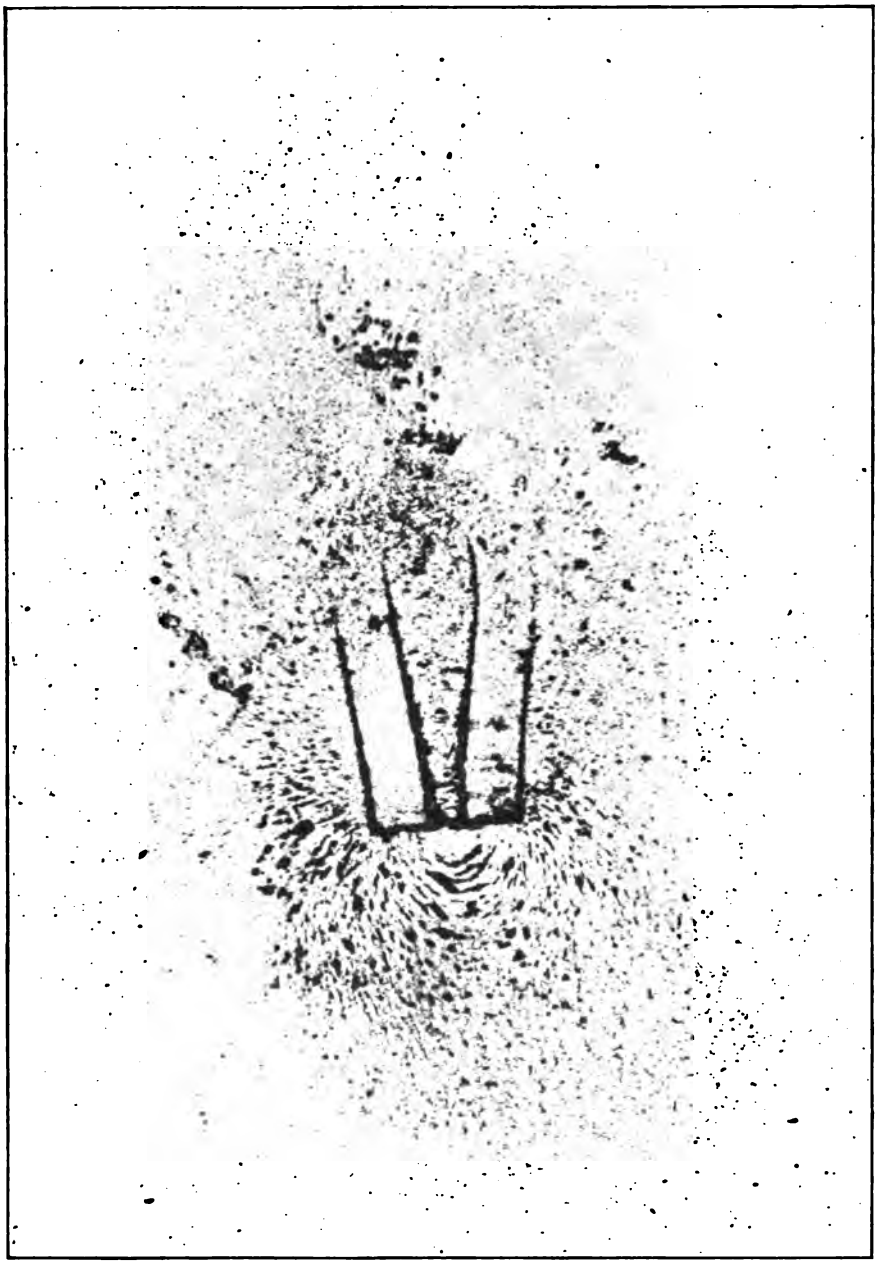

FIG. 22.—MAGNETIC FIELD FORMED BY SUBWAY DUST

subway or where the subway air emerged from some small opening into the sunlight in the streets, under which circumstances they glistened plainly.

Particles of subway dust, not iron, comprised bits of silica, cement, stone, fibers of wood, wool and cotton, molds, and undistinguishable fragments of refuse of many kinds.

Besides the dust which resulted from the grinding of metals, it was evident that the gradual wear and tear of many substances in the subway contributed to the dust.

Chemical Composition of the Dust.—The separate chemical analyses of eleven samples of accumulated dust from the subway showed the following average percentage composition: total iron, 61.30, including 59.89 metallic iron; silica, etc., 15.58; oil, 1.18; organic matter, 21.94, as shown in Figure 23. The results in full are given in Table X.

TABLE X

RESULTS OF CHEMICAL ANALYSES OF ELEVEN SAMPLES OF ACCUMULATED DUST FROM THE SUBWAY

Date, 1905.	Place.	Total iron.	Silica, etc., insoluble in acids.	Oil.	Volatile and organic matter.
		Per cent.	Per cent.	Per cent.	Per cent.
August 3	96th Street station	63.07	12.79	0.88	23.26
August 3	14th Street station	41.77	26.39	1.43	30.41
August 14	Grand Central station	67.35	12.65	1.23	18.77
August 18	23d Street station	54.36	20.50	0.99	24.15
August 17	Brooklyn Bridge station	45.72	21.79	1.97	30.52
August 21	33d Street station	69.66	12.34	0.91	17.09
August 21	Canal Street station	74.78	9.46	0.80	14.96
September 19	116th Street and Lenox Avenue station	66.69	13.84	0.96	18.51
September 19	Times Square station	68.42	7.45	1.00	23.13
September 20	18th Street station	59.84	17.94	1.43	20.79
September 20	28th Street station	62.58	16.28	1.42	19.72
	Average	61.30	15.58	1.18	21.94

Origin of Metallic Dust.—A large part of the metallic iron came from the wear of the brake shoes upon the steel rims of the wheels of the cars.

The wear upon the brake shoes was very severe. By weighing them when they were new and after they were worn out, and determining the number used, it was calculated by the operating company that 1 ton of brake shoes was ground up every month for each mile of subway.

The brake shoes consisted of cast iron with steel inserts.

There was also some loss to the rails and rims of the wheels and to the contact shoes which ran upon the third rail. Probably 25 tons per month would be a low estimate of the weight of iron and steel ground up in the whole subway every month.

Weight of Dust in Subway and Street Air Compared.—The average weight of dust found in the subway by the use of the sugar filters, using all of the results, was 61.6 mg. per thousand cubic feet of air, or 2.25 mg.

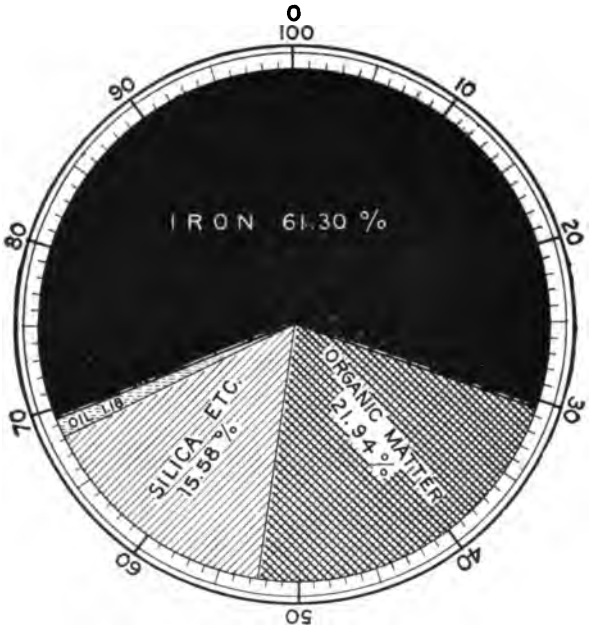

FIG. 23.—COMPOSITION OF SUBWAY DUST AS DETERMINED BY CHEMICAL ANALYSES OF ELEVEN SAMPLES

per cubic meter; in the streets, 52.1 mg. per thousand cubic feet, or 1.83 mg. per cubic meter; difference, 9.5 mg. The maximum amount found in the subway was 204 mg.

Twenty-three comparative tests were made to determine with particular care the weight of dust per thousand cubic feet of air inside of the subway and in the streets at the same time and as near the same place as possible. These showed an excess of dust in the subway of 47 per cent. over that outside. In five cases there was more dust outside, the greatest excess being 30 per cent. In the other eighteen cases the excess of subway dust over street dust ranged from 11 to 800 per cent.

Weight of Dust Inhaled by Passengers.—The weight of dust which the average passenger inhaled in one-half hour in the subway was very slight. Assuming that 360 c.c., or 22 cubic inches, of air were taken in at each breath and that the passenger breathed eighteen times a minute, the total quantity of air which passed into the lungs in half an hour was about 6.88 cubic feet, or 6.50 cubic meters. Using the average of all results, or 61.6 mg. per thousand cubic feet, as the weight of dust suspended in the atmosphere, it appears that the average passenger took into his nose or mouth .42 mg. of dust in a ride of half an hour.

Variations in the Amount of Dust.—The amount of dust found in the air of the subway varied with a number of circumstances.

More dust was found at the arrival ends than at the departure ends of the station platforms. This was probably due to the fact that the brakes were applied near the arrival ends, and to the fact that the currents of air from incoming trains helped to carry dust from those sections of the subway which lay between stations to the platforms.

The stations where the greatest weights of dust were found were express stations; there the amount of metallic dust formed by the braking of the trains was much greater than at the local stations and the travel from the streets greatest.

Bacteria.—The numbers of bacteria found in the dust of the subway were usually smaller than the numbers found in dust which had accumulated outside.

The average result of thirty samples of dust which had accumulated in the subway was 500,000 bacteria per gram of dust. The average obtained from six samples of dust which had accumulated under what appeared to be comparable circumstances in different buildings in New York was 600,000.

The largest number of bacteria found in a sample of subway dust was 2,000,000.

FINAL CONCLUSIONS

A review of the results of the investigation warrants, in my opinion, the following brief statement of the most essential facts determined with respect to the quality of the air.

According to usual sanitary standards, based on chemical and bacteriological analyses, the general air of the subway was always and everywhere satisfactory. The air in the cars in winter is not included in this statement.

According to public opinion, based on the testimony of the senses, the air was everywhere unsatisfactory, especially during the summer months.

My own conclusion was that the general air, although disagreeable, was not actually harmful, except, possibly, for the presence of iron dust. The strong draughts in winter at the stations and the lack of sanitary care exercised over the subway were, however, worthy of careful consideration in this connection.

The high temperature of the subway was its most noticeably objectionable feature. Had it not been for the heat, it is probable that the other unpleasant features would have failed to arouse serious protest. The heat, as is well known, was due to the conversion of electric power into friction. The amount of heat given off by the passengers was so small by comparison as to have had practically nothing to do with elevating the general temperature.

The heat was most objectionable in the mornings and evenings of summer during the hours of greatest travel and when the air outside was cooler than during the rest of the day.

The heat did not indicate that the air was vitiated or stagnant, as was popularly supposed. The subway was hot because a great deal of heat was produced in it, and stored by the materials of which the subway was built. That the heat did not escape rapidly enough for comfort was no proof that the air was not renewed often enough for health.

The carbon dioxide and oxygen analyses indicated that the products of respiration were rapidly carried away. Among the 2,200 carbon dioxide determinations, most of which were made in the subway, no sample of air was found which contained above 8.89 parts of CO_2 per ten thousand volumes, and this amount was found under circumstances which must be regarded as exceptional.

The average excess of carbon dioxide in the subway over that in the streets, 1.14 parts per ten thousand volumes, showed that the air was renewed with remarkable frequency. In the absence of a census giving the number of passengers in different parts of the subway at different hours, it was impossible to calculate just how frequently the air was renewed; but from such estimates as it was possible to make it seemed not improbable that the air of the whole subway was completely renewed at least every half hour.

It is true that the renewal occurred somewhat more frequently in some parts of the subway than in others, but the exchange was always

and everywhere abundant. We must except, of course, from this statement, the cars when closed, and other places where dense crowding occurred.

The controlling condition which regulated the extent to which the air was renewed was the freedom with which it could move in and out of the subway. The air was best where the subway was most open to the streets, and, conversely, it was least satisfactory where the subway was most enclosed. More blowholes would have greatly improved the conditions.

The movement of the trains set in motion the essential ventilating currents. This they did, first, by forcing subway air out and bringing street air in at openings; and second, by moving the air through the subway between openings.

It was fully demonstrated that there were no pockets or other places where air stagnated. Diffusion was everywhere rapid, complete, and satisfactory. I except the cars in these statements, as already indicated.

The fact that there were only about half as many bacteria found in the air of the subway as in the air of the streets under which the subway ran gave ground for the opinion that the bacteriological condition of the subway air was satisfactory, although too much reliance should not be placed upon this guide to its condition. Judgment on this point would have been more conclusive had it been possible to demonstrate that no more harmful bacteria existed in the subway than in the air outside. This was beyond the practicable possibilities of bacteriological technique.

The odors of the subway, like the heat and dust, were objectionable, apparently, chiefly because they were disagreeable. They resulted largely from the operation of the trains. They were, in my opinion, to a large extent preventable.

The sanitary significance of the characteristic black dust of the subway, containing, as it did, over 61 per cent. of metallic particles, remained to be considered at the close of the investigation. At the request of the Board of Rapid Transit Commissioners, this matter is now being studied by me.

NOTES ON THE CHARACTERISTIC CURVES OF THE DIRECT-CURRENT MACHINE

By HARRISON W. SMITH

THE following notes have been found useful in discussing the action of the direct-current machine. There is very little in the treatment that is in any way new, but the subject is here considered in more nearly complete form than is readily available elsewhere in English.

The Magnetization Curve.—When the armature current in a direct-current machine is zero the E. M. F. at the brushes is equal to that induced in the armature, and is given by

$$E_a = \phi N \frac{p}{a} \frac{S}{60} 10^{-8},$$

where ϕ is the flux per pole; N, the number of inductors; S, the speed in revolutions per minute; p, the number of poles; and a, the number of circuits in parallel in the armature.

Since in the given machine N, p, and a are constant, it follows that

$$E_a = kS\phi$$

where k is a constant.

The flux per pole is determined by the ampere turns nI, produced by the field magnet coils, and as n is constant for a given machine, it follows that

$$E_a = k'Sf(I).$$

The magnetization curve shows the relation between E_a and I. It is experimentally obtained by driving the machine at constant speed, and noting the terminal E. M. F. for different values of the field current I. The machine is, of course, separately excited, with no current flowing in the armature except the small current taken by the voltmeter.

Figure 1 shows such a curve for a 3-horse power machine at a speed of 1,100 revolutions per minute. Starting with the field current zero, the induced E. M. F. is approximately 10 volts, due to residual magnetism. As the current is increased to 0.15 ampere the E. M. F. rises, as

shown in curve I, in direct proportion to the field current, since up to this point the permeability of the iron is high and the ampere turns are required almost entirely to overcome the constant reluctance of the air gap. This portion of curve I is, in fact, very nearly a plot of the magnetization curve of the air gap. As the field current is

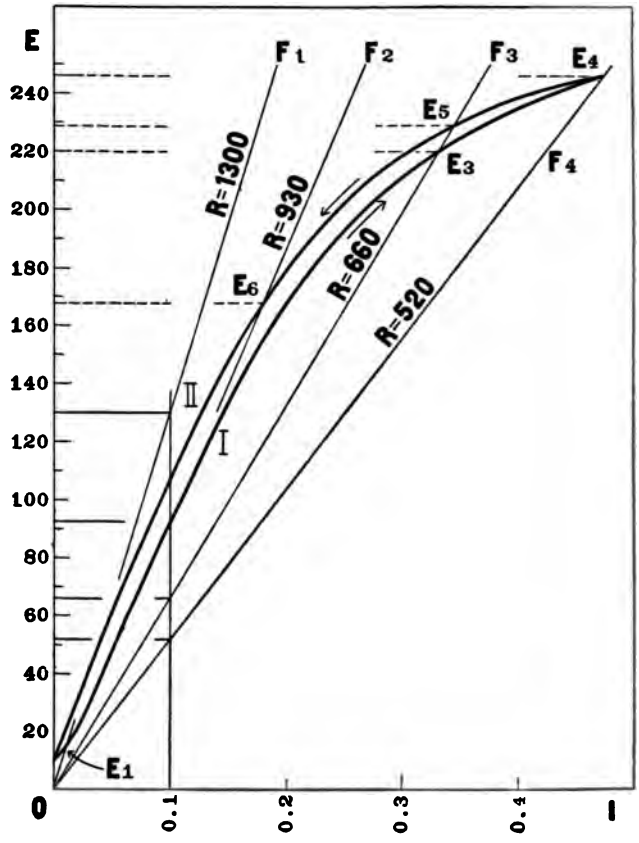

FIG. 1

still further increased, the E. M. F. rises less rapidly, for the iron is now approaching saturation and its permeability is decreasing. Continuing to increase the field current, the E. M. F. finally reaches the value E_4. If, now, the field current is gradually decreased, a different magnetization curve II will be obtained lying somewhat above I, owing to the effect of hysteresis. When the current is again zero the E. M. F. is 10 and the curve joins curve I, thus completing a portion of the hyste-

resis cycle for the magnetic circuit of the machine. The shorter the air gap of the machine, the steeper will be the curve for small values of field current and the further apart will the two curves lie.

This curve corresponds to a speed of 1,100 revolutions per minute; if it is desired to obtain the magnetization curve at any other speed, S, it is sufficient to multiply the ordinates of the given curve by the factor

$$\frac{S}{1100},$$

since for a definite field current the value of E_a is directly proportional to speed.

The Shunt Generator. — Let the machine be connected as a self-exciting shunt generator with a rheostat in series with the field for the purpose of varying the resistance of the field circuit. For any definite field resistance, we may plot the equation,

$$I_f = \frac{E}{R_f};$$

where I_f is the current in the shunt field circuit, R_f is the resistance of that circuit. The plot of this equation is a straight line through the origin. It is called the *field resistance line*, and four plots are shown for the values of field resistance 1,300, 930, 660, and 520. In general, any line through the origin represents some particular field resistance, of which the value can readily be found by noting the value of E at the point where the field resistance line intersects the vertical line through the point $I = 0.1$. For example, OF_1 shows that the field current must be 0.1 when terminal E. M. F. is 130; so that OF_1 corresponds to a resistance in the field circuit of 1,300 ohms.

The point of intersection of the field resistance line, with the magnetization curve, shows the only value of field current which corresponds to the same value of E. M. F. induced in the armature and impressed on the terminals of the field circuit. This point of intersection shows then the E. M. F. which the machine will generate if it is assumed that the induced E. M. F. is equal to the E. M. F. at the brushes; that is, if the machine is not loaded and the small IR drop in the armature due to the field current is neglected.

When the machine is running with the field circuit open the E. M. F. generated is 10 volts. If the field circuit is now closed and its resistance is 1,300 ohms, the E. M. F., E_1, will be given by the inter-

section of OF_1 with the ascending magnetization curve I. When the resistance of the field circuit is decreased to 930, it is apparent that OF_2 will practically coincide with curve I between points whose ordinates are, respectively, 30 and 80. This value of the field resistance is called the *critical resistance*, for it is evident that until the resistance is reduced to this point the machine will generate very little more than 10 volts. When, however, the resistance is made even slightly less than 930, the machine "builds up" rapidly. With $R_f = 660$ the machine generates E_8, and with $R_f = 520$ the terminal E. M. F. becomes E_4. If, now, the field resistance is gradually increased, the terminal E. M. F. will be found by the intersection of the field resistance lines with the curve II. It is evident that the E. M. F. which the machine will generate for a field resistance of 660 may be any value between E_8 and E_5, depending on whether the previous value of the field resistance was greater or less than 660.

In the future discussion only one of the magnetization curves will be considered, but it must be remembered that any deductions which are made from that curve will apply only to the operation of the machine, with increasing or with decreasing flux, according to which of the two magnetization curves is used.

External Characteristic of Shunt Generator. — Figure 2 shows the descending portion of a magnetization curve. The field resistance, corresponding to OF in this case, is given by the point B on the line OF, from which it appears that the resistance is approximately 500 ohms. Consider the conditions under which the field current has the value 0.35, the speed of the machine remaining constant. The magnetization curve M shows that the induced E. M. F. must be E_2, while the line OF shows that 0.35 ampere is maintained in the field circuit by an E. M. F. equal only to E_3. If the machine has no load, this is an

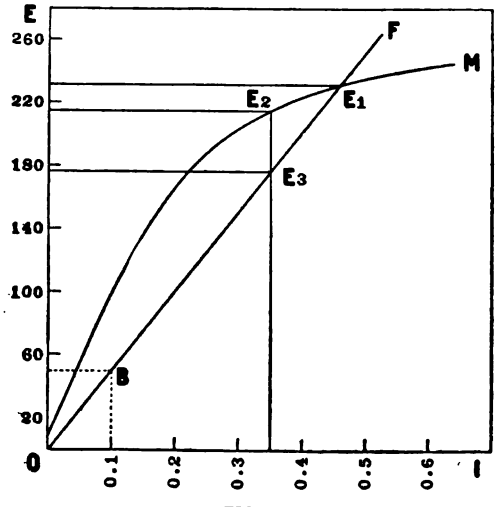

FIG. 2

impossible condition of operation, since the E. M. F., E_2, will produce a field current greater than 0.35, which, in turn, will produce an induced E. M. F. greater than E_2; the machine will build up to E_1.

When, however, a current flows in the armature of a machine the induced E. M. F. differs from the terminal E. M. F. by the IR drop in the armature. In the case of a dynamo,

$$E_a = E_t + I_a R_a,$$

where E_a is the induced E. M. F., E_t the terminal E. M. F., I_a the armature current, and R_a the total resistance of armature circuit from brush to brush.

From Figure 2 this equation is

$$E_2 = E_3 + I_a R_a,$$

from which

$$I_a = \frac{E_2 - E_3}{R_a}.$$

In this case $E_2 - E_3 =$ approximately 38 volts, while $R_a = 1$ ohm; so that the machine may be operating with field current $= 0.35$, provided the load is such that $I_a = 38$ amperes. In this way the external load characteristic of the machine may be plotted; for E_3 is the terminal E. M. F., while $I_a - 0.35$ is the current in the external circuit. By taking other values of the field current, any number of points on the characteristic may be obtained. It is obvious that the effect of armature reaction has been entirely neglected.

Relation of Motor and Dynamo Action. — As indicated above, the point of intersection of the magnetization curve and the field resistance line shows the terminal E. M. F. which the machine generates when no current flows in the armature. In Figure 2, then, the no-load terminal E. M. F. will be slightly less than E_1, since the terminal E. M. F. must be less than the induced E. M. F. by the amount of the $I_a R_a$ drop — in this case about 0.46 volt, since the field current is 0.46 ampere, approximately, and the armature resistance is 1 ohm. Figure 3 is a plot of the region near the point of intersection of the two curves, the scale being fifty times as great as that in Figure 2. It is assumed that the armature revolves at a constant speed and that the armature may either receive or deliver mechanical energy. It is also assumed that the terminals of the machine are connected to mains capable of variation in voltage and capable either of receiving or delivering electrical energy.

When the terminal E. M. F. is E_o the induced E. M. F. has the

same value, and no current flows in the armature; in this case the armature is receiving mechanical energy sufficient to overcome its friction and core losses, while the field current, equal approximately to 0.4625, is flowing in from an external source. Although the armature and field are connected as in any shunt machine, no current flows between them.

The terminal E. M. F., E_2, is chosen, so that $E_1 - E_2 =$ the IR drop in the armature due to the field current necessary to produce E_1. In this case the armature is generating the current necessary for the field, and no current is flowing between the machine and the external circuit.

When the terminal E. M. F. is E_6 the induced E. M. F. is E_5 and the IR drop is $E_5 - E_6 = 1.7$ volts; that is, $I_a = 1.7$ amperes. And since the field current necessary to produce E_5 is 0.458, the machine must be delivering to the external circuit a current $1.7 - 0.458 = 1.242$ amperes. For this field current the machine is, therefore, acting as dynamo, and is delivering a small amount of energy to the external circuit.

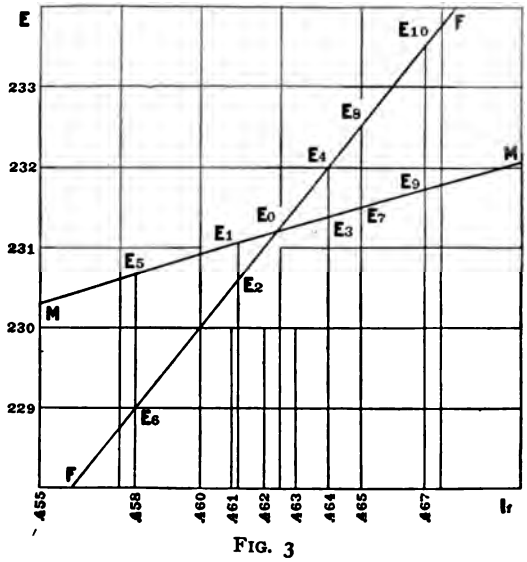

FIG. 3

When the terminal E. M. F. is E_{10}, corresponding on the field resistance line to

$$I_f = 0.467,$$

the induced E. M. F., as shown by the magnetization curve M, is E_9. In this case the IR drop in the armature is $E_{10} - E_9 = 1.8$ volts, and the armature current is, therefore, 1.8 amperes. Since the impressed E. M. F., E_{10}, is greater than the induced E. M. F., E_9, the machine must now be acting as motor, and as 1 ampere is the armature current necessary to run this machine as a motor at this speed without load, the additional 0.8 ampere will cause the armature to transmit mechanical energy to

the shaft to which it is connected. The current supplied from the external source is $I_a + I_f = 2.267$.

When the terminal E. M. F is E_8 the IR drop is $E_8 - E_7 = 1$ volt, so that the armature current is then 1 ampere, which is the current necessary to drive the armature as motor without load. The current delivered to the machine is $I_a + I_f = 1.465$, and the armature is neither receiving nor delivering mechanical energy.

When the terminal E. M. F. is E_4 the armature current is 0.6 ampere, which is not sufficient to supply the losses in the armature. This assists in maintaining the speed of the armature, but a small amount of mechanical energy must also be supplied through the shaft to which the armature is attached. In this case the source of electrical energy to which the terminals of the machine are attached furnishes the energy for the field circuit and a part of that necessary to drive the armature, the balance coming from the shaft to which the armature is attached.

The relation of motor and dynamo action may be stated briefly as follows:

When the terminal E. M. F. is below E_o the machine is acting as dynamo; when above E_o it is acting as motor.

When the terminal E. M. F. is below E_2 the machine is delivering electrical energy to the external circuit; when above E_8 the machine is delivering mechanical energy from its armature.

For any terminal E. M. F. between E_2 and E_8 the machine is receiving both electrical and mechanical energy.

Relation of Terminal E. M. F. and Speed.—In Figure 4 M_1 is the magnetization curve and OF the field resistance line for a given machine at a particular speed, S_1 : E_1 is the corresponding no-load terminal E. M. F. of the machine, acting as a shunt generator. If, now, the speed decreases to S_2, the new magnetization curve obtained, as already indicated, is M_2, and the terminal E. M. F. at speed S_2 is E_2. Since the field resistance line is not affected by change of speed, it follows that

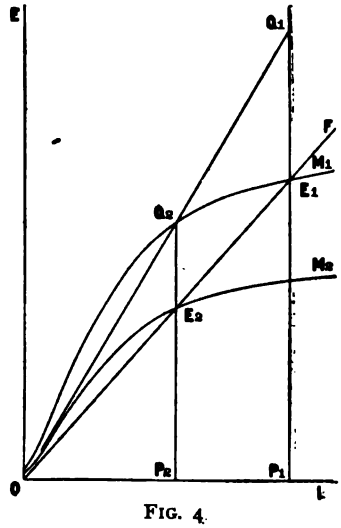

FIG. 4.

$$\frac{S_1}{S_2} = \frac{P_2Q_2}{P_2E_2} = \frac{P_1Q_1}{P_1E_1},$$

which gives a method of determining the terminal E. M. F. for any speed, as shown in Figure 5. M is the magnetization curve of a machine at $S = 1{,}100$ revolutions per minute, but the scale of abscissæ

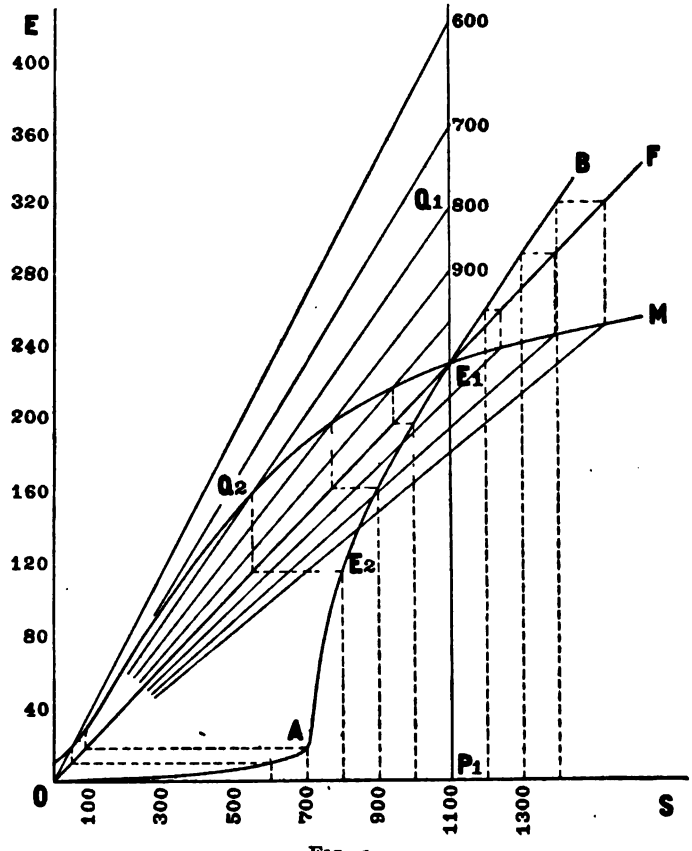

FIG. 5

on which M is plotted is not shown. OF is the field resistance line, and $E_1 = 230$ is the terminal E. M. F. at $S = 1{,}100$. To find the terminal E. M. F. at $S = 800$, for example, draw an ordinate through the point E_1 and locate the point Q_1, so that

$$\frac{P_1Q_1}{P_1E_1} = \frac{1100}{800}.$$

Draw OQ_1, and at the point of intersection, Q_2, of this line with M drop a vertical to the line OF, which gives the terminal E. M. F. for $S = 800$. E_2 is, then, a point on the curve of terminal E. M. F. and speed. This curve is shown in the figure as OAE_2E_1B.

The magnetization curve here shown is for an increasing field current, and the curve of the terminal E. M. F and speed shows, therefore, the rise in E as the machine is started from rest and the speed gradually increased. It will be noticed that E does not rise materially until the speed has attained 700, after which the rise is rapid. This is the *critical speed* of the machine.

Series Turns for Compounding. — The magnetization curve gives a convenient means of determining the number of turns of wire in the series coil necessary to give the same terminal E. M. F. at no load and full load. In Figure 6 M_1 is the magnetization curve for speed S_1, and OF_1 is the field resistance line for $E = 220$ at no load; OP is the shunt field current. Assuming 1 ohm resistance for armature and series coils and full-load armature current, 15 amperes, the induced E. M. F. necessary for full load is

$$E = 220 + 15 = 235.$$

The point B on the magnetization curve corresponding to 235 shows, then, the shunt field current, OQ, necessary to produce this induced E. M. F.; that is, the shunt field current must be increased by the amount PQ or the ampere turns must be increased by PQn, where n is the number of turns in the shunt coils. With the armature current of 15 amperes and the machine-connected *long* shunt, the number of turns in the series coils necessary to give the same terminal E. M. F. at no load and full load is

$$n' = \frac{PQn}{15}.$$

This calculation assumes no armature reaction; if this is to be allowed for, then PQn must be increased by the calculated demagnetizing ampere turns of the armature.

Effect of Change of Speed on a Compound Generator. — In Figure 6 M_2 is the magnetization curve at $S_2 = 1.3\ S_1$, and it is desired to determine the load terminal E. M. F. when the no-load value is 220, the series turns remaining as calculated for the previous case. In order that the no-load terminal E. M. F. may still be 220, the shunt field resistance must be made OF_2, with the corresponding shunt current OP'.

If HJ is then laid off equal to DC, it follows that $OQ'n$ gives the total ampere turns at full load, provided the E. M. F. impressed on the field is still 220. The point K on the curve M_2 shows, then, the induced E. M. F., and the point L, where $KL = BC$, shows the terminal E. M. F. The shunt field current, therefore, instead of being OP' must be that value corresponding to the point G on the field resistance line OF_2, so that the induced E. M. F. will actually be greater than K.

In order to determine the actual terminal E. M. F. of the machine when running at the higher speed with a load of 15 amperes, it is necessary only to find a position for the triangle $B'C'D'$ equal to the

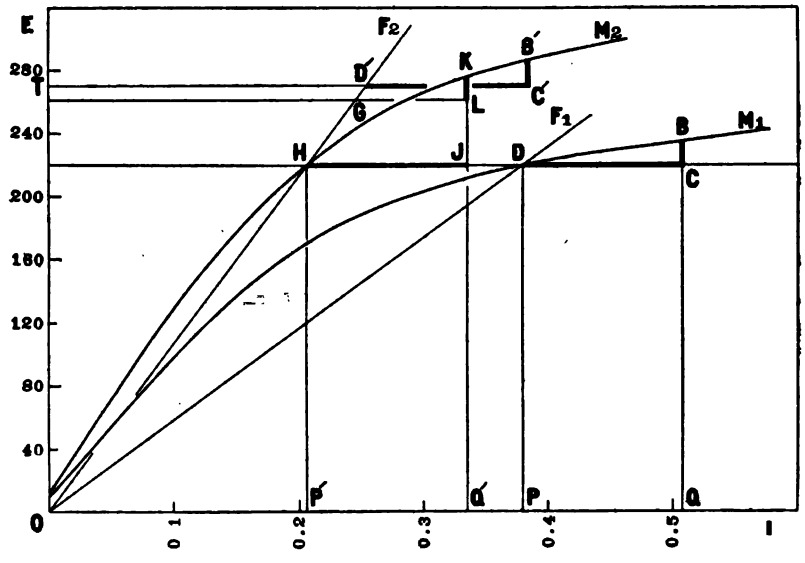

FIG. 6

triangle BCD, such that D' is on the field resistance line OF_2 and B' is on the curve M_2. Then the induced E. M. F., B', is 15 volts above the terminal E. M. F., C', while the total ampere turns $TC'n$ exceed the ampere turns due to the shunt coils $TD'n$ by the amount $D'C'n$, which constitute the ampere turns added by the series coils.

The load terminal E. M. F. is OT, or 270 volts, approximately, and the effect produced by raising the speed of a compound generator is then evidently to increase the relative effect of the series coils. If for a certain speed the characteristic curve of a compound generator is flat, for a higher speed the characteristic will be rising.

Relation of Speed and Field Resistance in Shunt Motor.— Figure 7 shows the magnetization curve M of a shunt machine at speed S_1, with 240 volts impressed on the terminals of the machine; OF_1 is the field resistance line corresponding to this speed, provided the armature IR drop is neglected; and it appears that the field resistance is approximately 580 ohms. Suppose now that it is desired to increase the speed to S_2. The equation of induced E. M. F. is $E_a = kS\phi$.

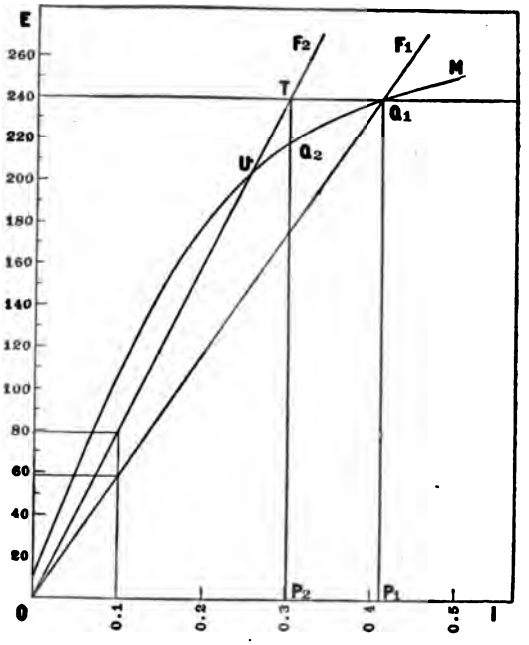

FIG. 7

And in this case, since the impressed E. M. F. is constant at 240 volts, the induced E. M. F., E_a, is constant also, and is assumed equal to 240. The equation becomes, then,

$$S = k' \frac{I}{\phi},$$

from which

$$\frac{S_2}{S_1} = \frac{\phi_1}{\phi_2};$$

but since the magnetization curve M is obtained by running the machine at constant speed,

$$\phi = k'' E_a,$$

where E_a is any ordinate on the magnetization curve.

We have, then,

$$\frac{S_2}{S_1} = \frac{k'' P_1 Q_1}{k'' P_2 Q_2},$$

or

$$P_2 Q_2 = \frac{S_1}{S_2} P_1 Q_1.$$

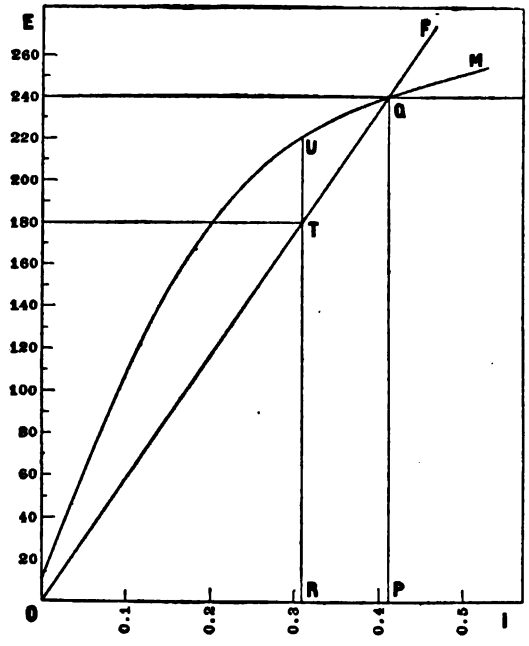

FIG. 8

For any value of S_2, P_2Q_2 is calculated, and the point Q_2 is located on the magnetization curve. OP_2 is then the field current necessary for speed S_2, and this current is maintained by the constant impressed E. M. F. = 240. Therefore the new field resistance line is OF_2 and the corresponding field resistance is approximately 790 ohms. The point of intersection U of the new field resistance line OF_2, with M, shows the E. M. F. which, impressed upon the machine, would drive it at speed S_1, with the field resistance = 790.

Effect of Terminal E.M.F. on Speed of Motor. — In Figure 8 OF is the field resistance line for speed S_1, and OP is, therefore, the field current corresponding. If the terminal E. M. F. is decreased from 240 to 180, the new speed may be found as follows:

Since
$$E_a = kS\phi,$$
$$\frac{S_2}{S_1} = \frac{E_2}{E_1}\,\frac{\phi_1}{\phi_2},$$

and we have merely to determine from the curves the values of E_2E_1 $\phi_1\phi_2$ in order to calculate S_2. From the field resistance line $E_1 = PQ$, $E_2 = RT$, and from the magnetization curve $\phi_1 = k''.PQ$, $\phi_2 = k''.RU$. So that

$$S_2 = \frac{RT.k''.PQ}{PQ.k''.RU}\,S_1 = \frac{RT}{RU}\,S_1.$$

It is evident that curve OAE_2E_1B in Figure 5 is a plot of terminal E. M. F.. and speed of a motor as well as that of a dynamo.

As regards motor action, this curve represents the rise in speed, as the terminal E. M. F. is gradually increased from zero. It should be remarked, however, that with the low values of terminal E. M. F. the actual performance of the machine departs largely from that indicated by the curve, owing to the relatively large effect of armature reaction when the field is weak.

Speed Curve of Series Motor. — The magnetization curve M of a series machine is shown in Figure 9 for speed = 800. The resistance

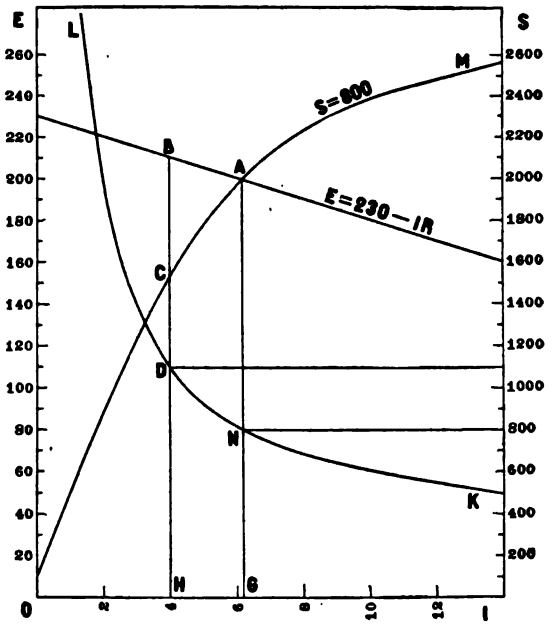

FIG. 9

of this machine, including armature, field, and brushes, is 5 ohms, so that with an impressed E. M. F. = 230 volts the induced E. M. F. must be $E_a = 230 - IR$, where I is the current through the machine. This equation is plotted in terms of induced E. M. F. and current. For speed = 800, curve M is also a plot of induced E. M. F. and current, so that the point of intersection A of the two curves shows the value of the current OG, which alone will correspond to a speed of 800; that is, OG is the only current which satisfies this equation:

$$230 - IR = E_a = Cf(I).$$

If, now, a scale of ordinates be chosen for plotting the curve of

speed and current, the point N will be a point on this curve, for $I = OG$ and $S = 800$.

To find the speed for any other current OH, we have, as before, the equation:

$$\frac{S_2}{S_1} = \frac{E_2}{E_1}\frac{\phi_1}{\phi_2},$$

where $$E_2 = HB, \qquad E_1 = GA;$$

$$\phi_1 = k''.GA, \quad \phi_2 = k''.HC;$$

from which $$S_2 = \frac{HB.k''.GA}{GA.k''.HC} = \frac{HB}{HC}S_1.$$

Substituting the numerical values in the equation, it is found that $S_2 = 1{,}100$; and, doing the same for other values of current, the curve $LDNK$ is plotted and shows the characteristically wide variation of speed of the series motor.

BOOK REVIEWS

THE INDUCTION MOTOR[1]

THE power and elegance of the graphical method for the solution of alternating current problems are never more convincingly illustrated than in the use of the circle diagram for the determination of the performance of induction motors. The original paper of Heyland's, appearing in the *Elektrotechnische Zeitschrift*, October 11, 1894, did not at first receive the attention which its importance seems to warrant. In recent years, however, the method therein set forth has been generally adopted.

The treatment given in the pamphlet indicated gives a sufficient idea of the plan to be followed to enable it to be applied by student or engineer, and the examples of detailed working out for motors of various capacities are extremely helpful.

A mere suggestion concerning the induction generator and an all too brief discussion of the single-phase induction motor are added.

H. E. CLIFFORD.

DESIGNS FOR SMALL DYNAMOS AND MOTORS[2]

THE work includes twenty-two designs of various types of generators and motors of small capacity for direct and alternating current service. They are well worked out and undoubtedly are of value as indicating the lines along which such designs should be carried. But, after all, designing is an art, and is most certainly not to be learned from any book. Such books, as a rule, are useful only in that they illustrate the applications of the fundamental principles of the electric and magnetic circuits.

H. E. CLIFFORD.

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[1] Alexander Heyland: A Graphical Treatment of the Induction Motor. Trans. from edition 2 by G. H. Rowe and R. E. Hellmund. New York: McGraw, 1906, 48 pp.

[2] Cecil P. Poole: Designs for Small Dynamos and Motors. New York: McGraw, 1906, 186 pp.

Stray Currents from Electric Railways[1]

This admirable treatment of the subject of stray currents includes a discussion of the general principles concerning leakage currents and their distribution in any circuit, the measurement of such currents, and the measures which may be taken to prevent them or reduce their effects to a minimum.

The book has a special force when one considers the very small amount of trouble which has been experienced abroad from such currents. An excellent bibliography is added by the translator.

H. E. Clifford.

A Polyglot Technical Dictionary[2]

The dictionary under review is compiled upon a novel plan; instead of the items being arranged alphabetically they are classified and fully illustrated, so that one seeks a definition from the illustrations rather than from the word. But in case one desires to look up a particular word, there is provided an alphabetical index which refers to the definition by page and paragraph. This index is in two parts: English, German, French, Italian, and Spanish in one alphabet, and the Russian in a second alphabet.

The arrangement of the main part of the dictionary is one that would seem to be particularly useful for persons desiring to write in a foreign language. For example, there are fifteen pages devoted to the mechanical transmission of power, and there are given not only words, but phrases used in reference to machinery of this kind. These being arranged together with illustrations, comparison is easy, and one may readily select the word or phrase that would be most appropriate.

In reading, one would use the alphabetical index, which, referring to the illustration, makes long definitions unnecessary.

Although this American edition is published in New York, with English title-page and preface, the book is distinctly of German manu-

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[1] Carl Michalke: Stray Currents from Electric Railways. Trans. by Otis Allen Kenyon. New York: McGraw, 1906, 101 pp.

[2] K. Deinhardt and A. Schlomann: Illustrated Technical Dictionary in Six Languages — English, German, French, Russian, Italian, Spanish. Vol. I, Elements of Machinery and Metal and Woodworking Tools. New York: McGraw, 1906, 403 pp., 12mo. $2.00 net.

facture, and in some cases the English equivalents given are rather literal translations of German expressions than English technical terms. For example, *Ein Zeichnung in Blei auffertigen* we should render, "To draw in pencil," instead of "in lead." "To draw views of a machine part" is not English, but the German *Einen Maschinenteil in Ansicht darstellen* rendered in English words. To mention a few more cases where the terms given do not correspond at any rate to American usage, the hatchet represented on page 191 is a broadax; the familiar rat-tail file appears on page 175 as a "needle file," and the three-cornered file is called a "three-square file"; and on page 201 the ordinary soldering iron is called a "soldering copper" or "copper bolt." These lapses of English make one wonder how far the corresponding expressions in French, Spanish, and Italian correspond actually to the usage in the countries where those languages are spoken.

A Chemical Cram Book[1]

In his preface the author explicitly disclaims any intention of writing a text-book in the ordinary sense, stating that his book is primarily intended as an aid for those rapidly reviewing the subject while preparing for examination.

Educators will probably differ as to whether special study for an examination, considered as an ordeal, is a desirable thing for the student. Nevertheless, so long as examination marks have far-reaching consequences for the candidate, special preparation will be made, and books like the one before us will be in demand. Of this it must be said that it is distinctly good of its kind. After a brief survey of the fundamental theories of the science, the various classes of organic compounds are taken up in detail, the methods of preparation, properties, chemical behavior, and constitution being discussed concisely in numbered paragraphs. The information is reliable and up to date, and in his generalizations the author has succeeded admirably in securing brevity of statement at a minimum sacrifice of accuracy or clearness. The arrangement of the pages is pleasing to the eye, and the type, paper, and binding are all to be commended. F. J. Moore.

[1] Dr. Kurt Dammann: Kurzes Repetitorium der Organischen Chemie für Studierende. Freiburg in Br. Herder, 1906.

PROCEEDINGS OF THE SOCIETY OF ARTS

FORTY-FIFTH YEAR, 1906-1907

BOSTON, October 25, 1906.

THE 625th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, October 25, 1906, at eight o'clock, fifty-five being present. Professor Louis Derr presided.

Mr. Wesley C. Gilman was elected a member of the Society.

Dr. George W. Pierce, of Harvard University, gave an interesting and instructive address on "The Measurement of Electric Wave Lengths in Wireless Telegraphy." By means of a Leyden jar and induction coil Dr. Pierce produced the oscillatory discharge used in wireless telegraphy, and showed how the measurement of wave lengths could be readily determined. He explained the various methods of connecting the sending apparatus, and showed by lantern slides the photographic reproductions which he had made of these oscillatory discharges. After answering numerous questions relative to wireless telegraphy, which were asked by members of the Society, Dr. Pierce was tendered a vote of thanks for his able and instructive address, and the meeting adjourned.

BOSTON, November 8, 1906.

The 626th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, November 8, 1906, at eight o'clock. One hundred and fifty-five persons were present. Mr. James P. Munroe presided.

Mr. William Lyman Underwood gave an exceedingly interesting and instructive talk on "The Work of the River Drivers in the Maine Woods." Mr. Underwood spent two weeks in this locality, and took many photographs showing the progress of the work at every point.

BOSTON, November 22, 1906.

The 627th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, November 22, at eight o'clock. About sixty persons were present. Dr. William T. Sedgwick presided.

The name of Dr. Robert P. Bigelow was presented to the Society for election to the Executive Committee, to fill the vacancy caused by the resignation of Mr. George W. Blodgett, and he was duly elected.

Dr. George A. Soper, of New York, gave an exceedingly interesting and instructive talk on his recent investigations of the air in the New York subway. Although the number attending the meeting was not large, the brief discussion which followed the address showed the interest taken in the subject. Dr. Soper's paper, containing much interesting data, will be published in full in the March number of the TECHNOLOGY QUARTERLY. The thanks of the Society were extended to the speaker, and the meeting adjourned.

BOSTON, December 13, 1906.

The 628th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, December 13, at 8.25 o'clock. About sixty persons were present. Professor C. H. Peabody presided.

Mr. Alexander E. Brown, Vice-President and General Manager of the Brown Hoisting and Conveying Machinery Company, of Cleveland, Ohio, spoke on the application of hoisting machinery to shipbuilding purposes.

Mr. Brown's wide experience in the design and construction of hoisting machinery made his address one of importance and interest, especially to those who are connected with work along construction lines.

Mr. Brown's remarks were confined to the cantalever type of crane, for the design of which his company is responsible; but as he was one of the pioneers in this line of work, the history of the cantalever crane is the history of the introduction of crane service to modern shipbuilding.

Owing to the lateness of the hour, caused by the delay of trains on which the speaker arrived, no discussion followed the address. After the thanks of the Society were tendered to the speaker, the meeting adjourned.

BOSTON, December 27, 1906.

The 629th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, December 27, at eight o'clock. About seventy persons were present. Professor George F. Swain presided.

Mr. Richard L. Humphrey, of Philadelphia, spoke on the results of the recent San Francisco earthquake. Mr. Humphrey has spent much time in San Francisco studying the effects of the earthquake from an engineer's point of view, and presented a most interesting address, illustrated with lantern slides.

BOSTON, January 10, 1907.

The 630th regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, January 10, at eight o'clock. Fifty-three persons were present. Professor Dwight Porter presided.

Colonel E. H. Hewins, Chairman of the Executive Committee, spoke on the urgent need of passing the bill at present before Congress for the establishment of the Appalachian and White Mountain Forest Reserves. Colonel Hewins moved that the SOCIETY OF ARTS authorize the Executive Committee to prepare a set of resolutions to be presented at the meeting of the Society to be held January 24. The motion was seconded, and passed without discussion.

Mr. Henry E. Warren, Superintendent of the Lombard Governor Company, Ashland, Massachusetts, delivered a most interesting and instructive address on "The Governing of High Pressure Water Wheels." He covered the subject in a general way, and brought out many points interesting alike to the layman and the hydraulic engineer. At the close of the address he presented a number of lantern slides showing various installations of water power, the head of which varied from a few hundred feet to several hundred feet. The address was followed by a short discussion, and the meeting adjourned, after extending the thanks of the Society to the speaker.

BOSTON, January 24, 1907.

The 631st regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, Room 22, Walker Building, on Thursday evening, January 24, at eight o'clock, forty-three persons being present. Professor H. E. Clifford presided.

Colonel Edmund H. Hewins, on behalf of the Executive Committee, presented a set of resolutions urging upon Congress the passage of the Forest Reserve Bill. These resolutions had previously been printed and a copy sent to each member of the Society. After the reading of these resolutions, a motion was made that they be adopted and a copy sent to each member of Congress from Massachusetts, and the motion was passed without discussion.

Dr. Walter E. Winship, Engineer with the Gould Storage Battery Company, spoke on "Storage Battery Regulations." After the address Dr. Winship illustrated with lantern slides some storage battery installations. The thanks of the Society were expressed to the speaker, and the meeting adjourned.

BOSTON, February 14, 1907.

The 632d regular meeting of the SOCIETY OF ARTS was held at the Institute of Technology, in Room 22, Walker Building, on Thursday evening, February 14, at eight o'clock, thirty-three persons being present. Professor C. H. Peabody presided.

Mr. F. L. DuBosque, Assistant Engineer in the Marine Department of the Pennsylvania Railroad, spoke on "The Marine Interests of a Railroad." Mr. DuBosque referred to the peculiar problems of construction and transportation, but laid especial stress on the more interesting point of the transportation of cars and freight by means of car floats and barges, and he spoke briefly of the facilities for placing freight on wharves and on board ship. After the address many questions were asked the speaker, and several exceedingly interesting points were brought out.

The thanks of the Society were extended to the speaker, and the meeting adjourned.

WALTER S. LELAND, *Secretary.*

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Vol. XX JUNE, 1907 No. 2

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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Vol. XX JUNE, 1907 No. 2

THE PHOTO-PITOMETER AND WATER WORKS LOSSES

By EDWARD S. COLE

Read February 28, 1907

One of the foremost problems in water works engineering today is *waste*, which has grown to alarming proportions in many American cities, already involving vast expenditures for unnecessary extension of plants, besides adding an ever increasing burden in cost of operation. Let us briefly consider the nature of this waste and means for its control.

The ancient Romans struggled with a heavy loss of water from their costly aqueducts, as we are told by Frontinus, and water works men are still attacking the same old problem.

Among the effective instruments that are helpful in the study of waste is the portable *photo-pitometer*, which has greatly simplified the measurement of flow of water through the intricate network of our underground pipe systems.

These distribution systems, which are the most costly and vital part of a water works plant, consisting of a vast gridiron of cast-iron mains, aggregating hundreds of miles in the case of our large cities, with a total valuation of millions of dollars, have received far less scientific attention than the more conspicuous parts of a water works property. *Filtration* has benefited by the wonderful developments of sanitary

science, and a century of steam engineering has produced the high-duty *pumping engine;* but comparatively little has been done to improve the all-important pipe system.

The works manager has never had accurate information regarding the flow of water in the various parts of his pipe system without using expensive and cumbersome means. Costly extensions of mains have, therefore, been left to guess work and much money thrown away.

Analysis of consumption in districts has been well-nigh out of the question because of the great cost of existing methods for gauging the mains.

This lack of information is now unnecessary, for with the portable pitometer measurements of flow may be made cheaply at any point without loss of time, and there is no longer any excuse for permitting losses from the underground system to continue.

Pure water delivered under pressure through pipes which provide adequate fire capacity is by no means a cheap product, as a few figures may show.

The actual cost of supplying one million gallons of water in many of our American works varies widely from about $20 in some of our large cities to $300 or more in the case of some small plants unfavorably situated. The average for twenty-two cities reported to the New England Water Works Association for 1904 was about $92 per million gallons for operating expenses and interest on bonds. This list includes no city larger than Cleveland, Ohio, where the reported cost was about $23. In Chicago the cost of water has been estimated at $19 per million gallons on the same basis. There, for example, the distribution system has 2,000 miles of mains from 4 to 48 inches in diameter, valued at $16,000,000, or one-half of the cost of the entire Chicago water works system, which is placed at $32,000,000.

With the growing demand for pure water supplies, involving vast expenditures for filtration works, the cost of water is increasing. For example, the city of Philadelphia is now building filters to cost over $30,000,000, and the necessity of reducing waste is therefore keenly appreciated.

Broadly speaking, *waste* is not the generous or even lavish *use* of water by consumers, but rather refers to willful and careless *misuse,* to the streams which run continually from faulty house fixtures and from leaky underground pipes; but water works losses include also the very serious problem of illegal *use* of water by large-metered con-

sumers, generally for trade purposes, through "by-passes," which rob the city of much needed revenue.

The slip of pumps, whereby our statistics of water consumption are falsified, is responsible for more trouble than has been supposed, for although loss of action in the pumps causes no waste of water, it nevertheless calls for additional pumping capacity at great expense and increases the fuel account.

Waste of water is *the* great evil in our American water works systems, and its effect upon city finances is twofold: First, in the futile attempt to fill the "sieve," which our leaky systems resemble, large appropriations are needed yearly to increase the pumping capacity; and, second, the pipe system needs continual reënforcement to maintain adequate fire service over and above the useless losses which drain its capacity.

Useless waste may amount to half the total supply of a city, or even more. For example, in his report on water measurements Mr. Dexter Brackett, C.E., concludes that half the total supply of the Metropolitan District is wasted, and a waste of one-half is evidently a serious matter. In New York City a recent report by Mr. James H. Fuertes, C.E., places the waste and unaccounted-for loss at 43 per cent. of the total supply, while J. R. Freeman, D.Sc., some years ago estimated the preventable waste in Manhattan at about 70 per cent.

In a recent report on water waste in Chicago, Mr. John Ericson, C.E., puts the probable waste at 76 per cent. of the total pumpage, and shows that $6,000,000 will be needed in the next ten years for tunnels and pumping plants alone if the present wasteful conditions go on. Whereas, if means are taken to control these losses, this great outlay may be avoided, and at the same time a greater saving made in extensions to the distribution system; for if one-half the supply is wasted the pumps must force twice as much water into the mains, and, since friction increases as the square of velocity, this doubling of the consumption through waste creates three times more loss by friction. The great cost of reënforcing a $16,000,000 pipe system does not need to be enlarged upon. Thus we see that the effect of waste on city finances *cannot* be ignored.

The principle of accurate accounting which is taken for granted in private business is peculiarly needed in water works management, but for lack of a cheap and portable meter it has as yet scarcely been applied in this country.

What is a fair and reasonable supply?

Let it be understood first of all that there can be no such thing as a standard per capita consumption by which cities may be compared one with another. Much of the controversy as to what constitutes an adequate water supply arises from lack of knowledge regarding the special requirements of different cities. It is folly to compare statistics of total per capita consumption without first separating trade and public uses from ordinary domestic demands. Then again the population per mile of main, the amount of lawn sprinkling per capita, and, above all, the relative luxury and personal habits of the several classes constituting the population of a city must be considered.

The very wasteful city of Buffalo, which has a total use per capita of over three hundred gallons, has a metered consumption for trade purposes alone of forty-six gallons per capita, more than the supply of Fall River for all purposes. Evidently such cities cannot be compared by their per capita consumption where they differ so widely in the trade use of water.

There is, however, ample opportunity for a study of definite and carefully classified uses, such as that made recently for the Metropolitan Water District (Boston) by Mr. Dexter Brackett, C.E., in which he gives the following analysis, based largely upon actual measurement:

Domestic use	25.0 gallons per capita
Manufacturing and trade use . .	23.5 gallons per capita
Public use	7.0 gallons per capita
Total	55.5 gallons per capita

or less than sixty gallons daily for each man, woman, and child. Whereas the Metropolitan District actually receives about 122 gallons per capita daily.

In other cities we have a reported total consumption per capita ranging from that in

Buffalo	over 300
Pittsburg and Philadelphia	over 200
New York, Chicago, St. Louis, and Boston .	from 130 to 160
Providence, Worcester, Fall River, and Milwaukee [largely metered cities]	40 to 80

Abroad one finds such cities as London, Liverpool, Manchester, Glasgow, etc., reporting from thirty to sixty gallons. But there we

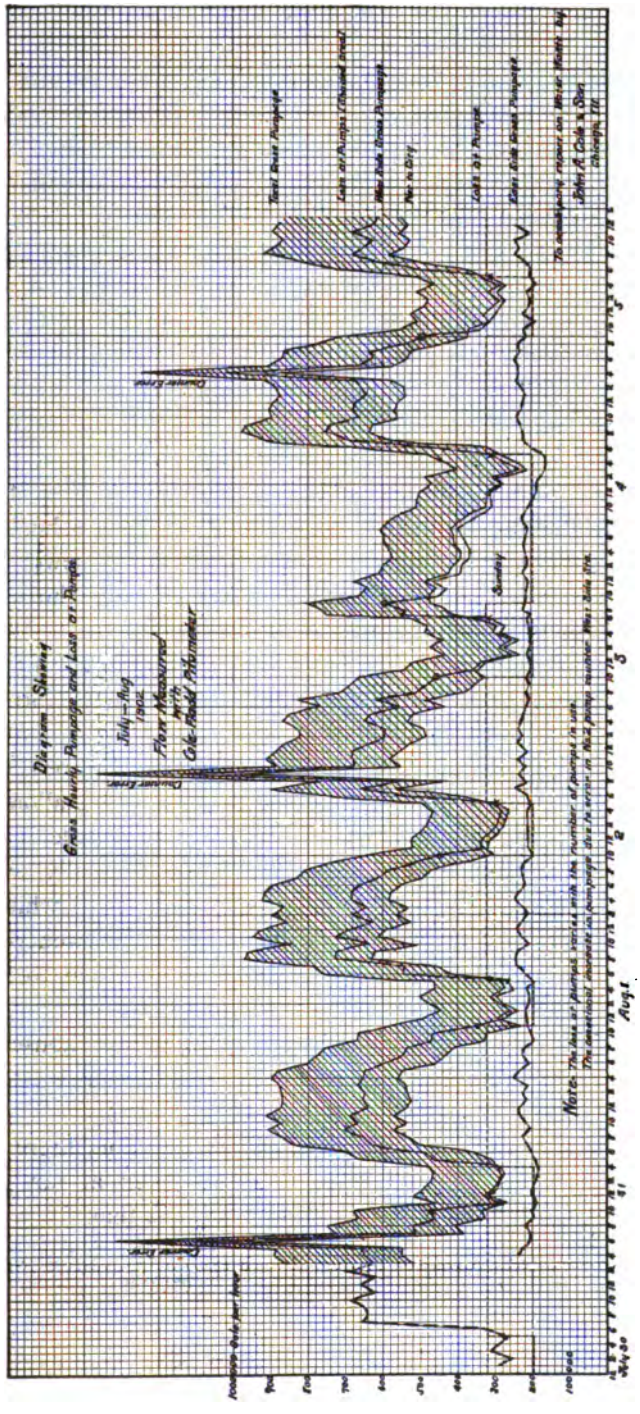

FIG. 1.—TOTAL PUMPAGE TO CITY AS MEASURED BY PITOMETER AND THE REPORTED PLUNGER DISPLACEMENT FOR SEVEN DAYS
Shaded area represents the loss by "slip"

find that a policy of waste restriction has been highly developed, which we will consider in detail later.

In this wide range of supply to American cities the reported figures are liable to be in error from an unsuspected slippage in the pumps. One of the first discoveries to the credit of the pitometer was in a city of about 125,000 population, which had been reporting 33 per cent. more water than was actually leaving the pumps.

Since this illuminating experience, pitometer tests show that leaky pumps are the rule rather than the exception, and a loss of from 25 to 50 per cent. is by no means unheard of even in engines of the highest type and largest size.

A wide variation in per capita consumption is due, as has been shown, to *trade use*, which will vary as cities are largely residential or are devoted mainly to commerce and manufacture.

Public uses, while but a comparatively small part of the total consumption, including the supply to public buildings, schools, hospitals, etc., are an important element. Street sprinkling, sewer flushing, and fire extinguishing call for attention when reducing the supply to a per capita daily standard.

Domestic consumption varies, as already stated, according to the habits of the people, and upon this point we are able to form a well-based opinion as to what constitutes a reasonable allowance.

In Worcester, Massachusetts, the total domestic use per capita, as shown by meters, is 16.8 gallons, varying from twelve gallons in the cheaper houses to twenty-three gallons in the best residence streets.

In Fall River the average class of dwellings, generally with bath and water-closet, use about eight gallons per capita daily, while in the most expensive houses the consumption is reported as twenty-five gallons. Boston apartment houses varied from about sixteen to fifty-nine gallons per capita daily, according to cost.

We should remember that these figures are for actual house requirements by meter measurements, and take no account of waste in the service pipe beyond the meter or in the street mains.

In Columbus, Ohio, a city with 125,000 population, there were in 1902 8,000 meters, and among 2,000 of these, taken at random from the books, 650 indicated a daily consumption of less than fifteen gallons per capita. It follows, then, that in fully one-third of all the houses in this city the use per capita was less than fifteen gallons per day, based on the meter statements. These 2,000 meters, as a whole, averaged sixty-five gallons per capita daily.

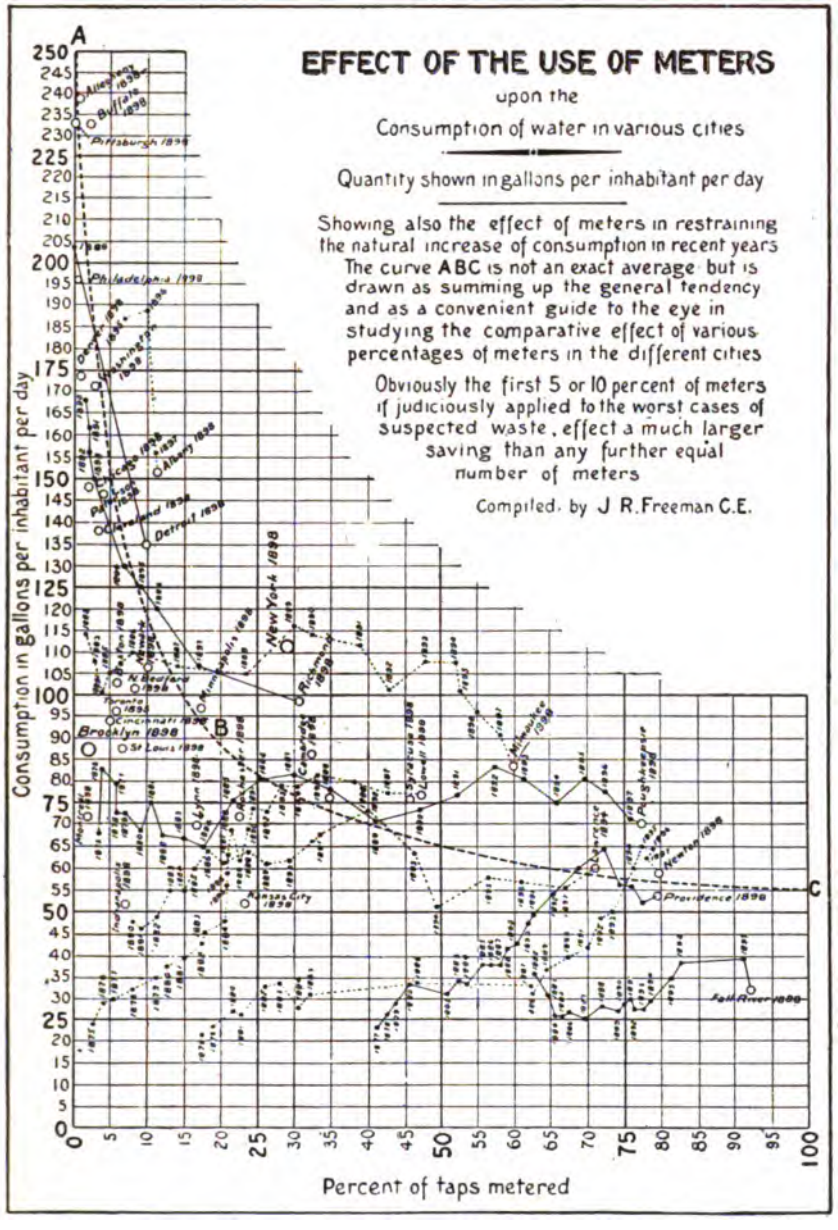

FIG. 2.—DIAGRAM ILLUSTRATING THE COMPARATIVELY SMALL SAVING BY THE APPLICATION OF METERS TO MORE THAN 40 PER CENT. OF THE CONSUMERS

An examination of the hourly records of pumpage in cities is very convincing as to the existence of waste. The notable feature of such records is that the apparent consumption is always high, even at the dead of night.

While we cannot judge of the relative wastefulness in various cities by a comparison of the per capita consumption, we find in reviewing statistics that the use of meters is always attended with a reduction of waste. An interesting diagram (Fig. 2), prepared by Mr. John R. Freeman, gives the use per capita of many cities and the percentage of taps metered in each. No better argument for the judicious use of meters should be needed, for the excellent effect of placing meters on about 40 per cent. of the consumers is plainly shown. This diagram also indicates that it is not economy to place meters upon more than about 40 per cent. of the premises taking water, if all trade uses and the more wasteful consumers are included.

We should also note that these communities having the largest percentage of taps metered and the smallest consumption are cities of moderate size. Here undoubtedly the demands are not as great as in the largest cities, where, as a rule, less than 10 per cent. of the taps are as yet metered. A meter system should always be supplemented by work for restricting losses in street mains and services beyond the reach of meters. There are many sources of waste, of which the chief may be defined as follows:

1. Defective plumbing in houses.
2. Willful waste, such as allowing water to run to prevent freezing, extravagant use of hose, etc.
3. Leaks beyond the consumer's premises in mains and service pipes.
4. Slip of pumps and careless station use.
5. Surreptitious uses not paid for.

(1) *Defective plumbing* is a well-known source of waste, largely due to our American habit of permitting the use of cheap and inferior fixtures, and the ordinary house meter certainly stands guard over it, for a meter makes each householder his own inspector. The admirable English practice of requiring all fixtures to pass official inspection could, if adopted in this country, accomplish great results.

(2) *Willful waste* undoubtedly exists. Many persons will let a stream of water run rather than pay a plumber for making repairs, and few realize how much a small stream will waste in twenty-four

hours. An ordinary faucet on a first floor may run as much as 5,000 gallons a day.

(3) *Leaks* beyond the reach of the house meter are undoubtedly larger than supposed, as evidenced by recent tests and meter comparisons.

In a large number of cities, having practically every tap metered, there is usually a discrepancy of from 30 to 50 per cent. between the total pumpage and the total meter registration. This unmistakable loss still remains after allowing for unmetered public uses, fires, and for slip of pumps. The inevitable conclusion is that water is leaking underground from mains and services. Now in the 2,000 miles of water mains in Chicago, for instance, there are fully one million joints of all sizes in mains alone, and no one knows how many leaks from a mere drip to a heavy stream may be flowing into the sandy soil or near-by sewer without showing on the surface. A distribution system of this size will also have several hundred thousand small service pipes, with an average length of perhaps 50 feet. These pipes are often of wrought iron, which may soon be perforated by corrosion. Leaky, broken, and abandoned service pipes are responsible for much waste which, because of a porous soil, may not give warning at the surface.

Mains should certainly be tight and services sound. In an entirely new system, ranging in size from 4-inch to 16-inch cast-iron pipe, under fifty pounds pressure, and before any service pipes were attached, a test is reported, showing a leakage of but one gallon per minute per mile of main. Such tests as this indicate that a well-laid system may be practically tight.

Some have thought that a large allowance should be made for defects in meters, but the large loss of water unaccounted for by total meter registration can hardly be caused by error in the meters themselves. In 1897 Mr. John A. Cole, C.E., had careful tests made of 1,064 meters in Des Moines, Iowa, which had been in use from one to fifteen years. Meters suspected of slip were mainly chosen, and the results showed an average loss of registration of only about 1½ per cent.

(4) *Slip of Pumps and Careless Station Use.* — All of the reported pumpage does not reach the mains because of what is known as "slip" and "station use" at the pumps. It is customary to make only a very small correction for this loss, and, in fact, the statistics of most cities are based upon the full amount of water displaced by the pump plungers, the almost universal method being to multiply the recorded strokes of each engine by the theoretical number of gallons displaced

by its plungers per stroke. The only merit of this method lies in its simplicity. That it is liable to gross error has been found on many occasions when the actual discharge from a pump has been measured and compared with the counter record. Discrepancies of 25 to 40 per cent. and more have been repeatedly found in pumping engines by pitometer tests.

This loss should always be determined and deducted from the reported supply to a city. Slip at the pumps is not only misleading,

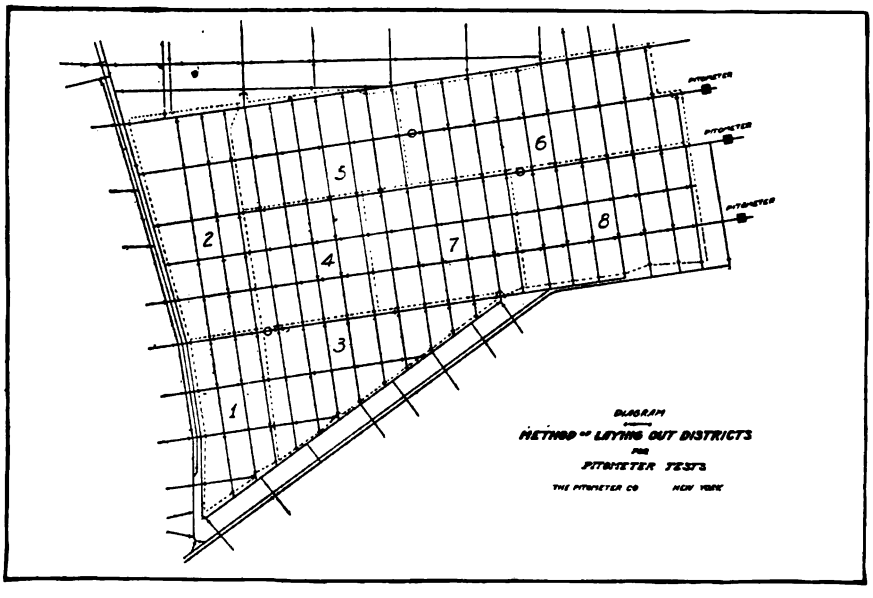

FIG. 3.—A SECTION OF THE NEW YORK CITY PIPE SYSTEM SHOWING METHOD OF GAUGING BY PITOMETERS AND SUBDIVISION

but requires the same pump capacity, steam, and fuel as though the full plunger displacement were discharged into the mains.

This slip leakage, developed by wear of the plunger and valves, permits the water to "slip" by, simply churning back and forth, doing no good, but absorbing power and valuable pumping capacity, which is worse. Such loss is more likely to become serious in the horizontal inside-packed type of pump. The presence of sand or grit in the water will cause wear between plunger and ring, valve and seat, until in a few months the loss may be enormous.

Electrolysis has been the cause of much deterioration of mains and

services in a large number of cities. The leaks so produced are difficult to find, and the full extent of the damage can be discovered only by making a careful and minute survey of the system, street by street, by voltmeter and pitometer.

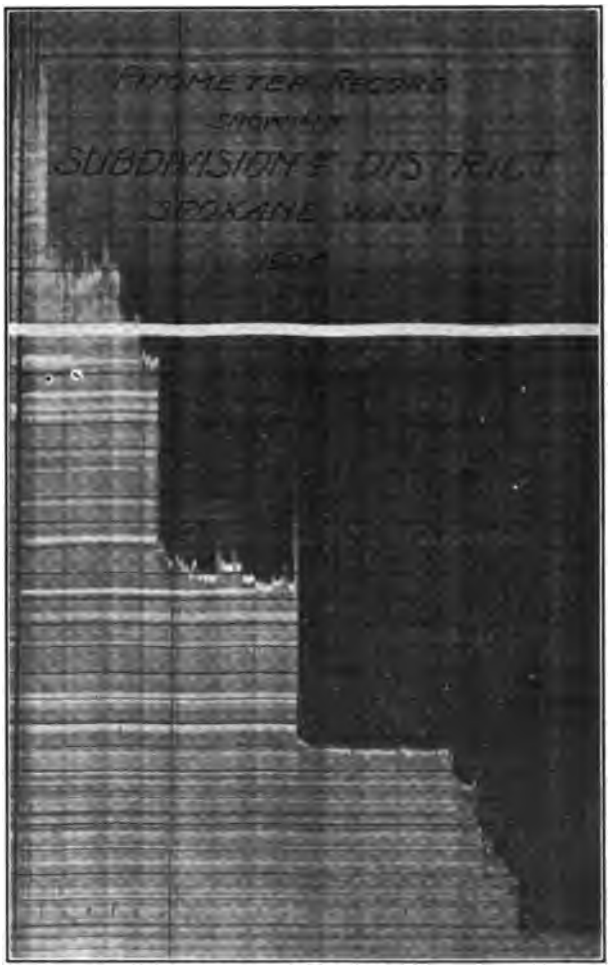

FIG. 4.—A PITOMETER RECORD REDUCED SHOWING "DROP" IN FLOW AS GATES ARE SHUT

The extent of water waste has, perhaps, been sufficiently described, and the remedy may now be considered.

In a water-waste investigation a city is divided into large districts, closing all the main gates but one, placing a recording pitometer on the

inlet to the district (Fig. 3), and keeping a record of the inflow. This total use in connection with the district population and the amount registered by the private meters will give a good idea of the wastefulness of the section, taken as a whole, the rate of night use being most significant. In case the district shows a reasonable rate it may be passed by, thereby saving the expense and trouble of house to house inspection.

If, on the other hand, an excessive consumption per capita is indicated, the next step is to analyze the supply by streets, using the pitometer to record the "drop" in flow as valves are closed one after another. All streets do not use water at the same rate per tap, and for this reason it is easy to find an unusual flow. When the night waste has been localized within a few blocks this smaller section is enclosed by itself and supplied through its own waste meter.

Then, if necessary, the curb cocks are closed one after another at night, the waste meter at the same time continuously recording the rate of flow, so that when a house is reached which has a leaky service pipe or fixtures the pitometer on the main will, on closing the curb cock, record a "drop," which is the rate of waste. In this way a record showing the condition of every house on the street is obtained and waste is located, which can be further defined by house to house inspections. The waste meter record not only locates the loss on certain premises, but measures it exactly.

This American method by the use of the pitometer is a development of the long established Deacon system, which, although still very much depended upon in England, has not proved popular in this country, although for several years it was used in Boston with success.

Every large city should organize its own department for the systematic detection of waste according to some such plan as has been outlined. The work calls for the intelligent and skilled supervision of an engineer, and must be persistently followed up for years, if need be, to secure the final results. The time required to traverse a square mile depends on the number of waste meters employed and upon the physical condition of the pipe system. Several districts may be inspected at the same time under the direction of one competent head. Experience has amply proved the value of such work, for its results are felt at once, and the cost is repaid out of savings as the investigation proceeds.

The increase of income and the saving of expenditure for new pumps and mains will net millions of dollars to taxpayers. Purification

works, which sooner or later will be demanded in many of our large cities, can be built from funds so saved without becoming a burden. *Waste prevention* and *water purification* are now the order of the day, and they ought to go hand in hand.

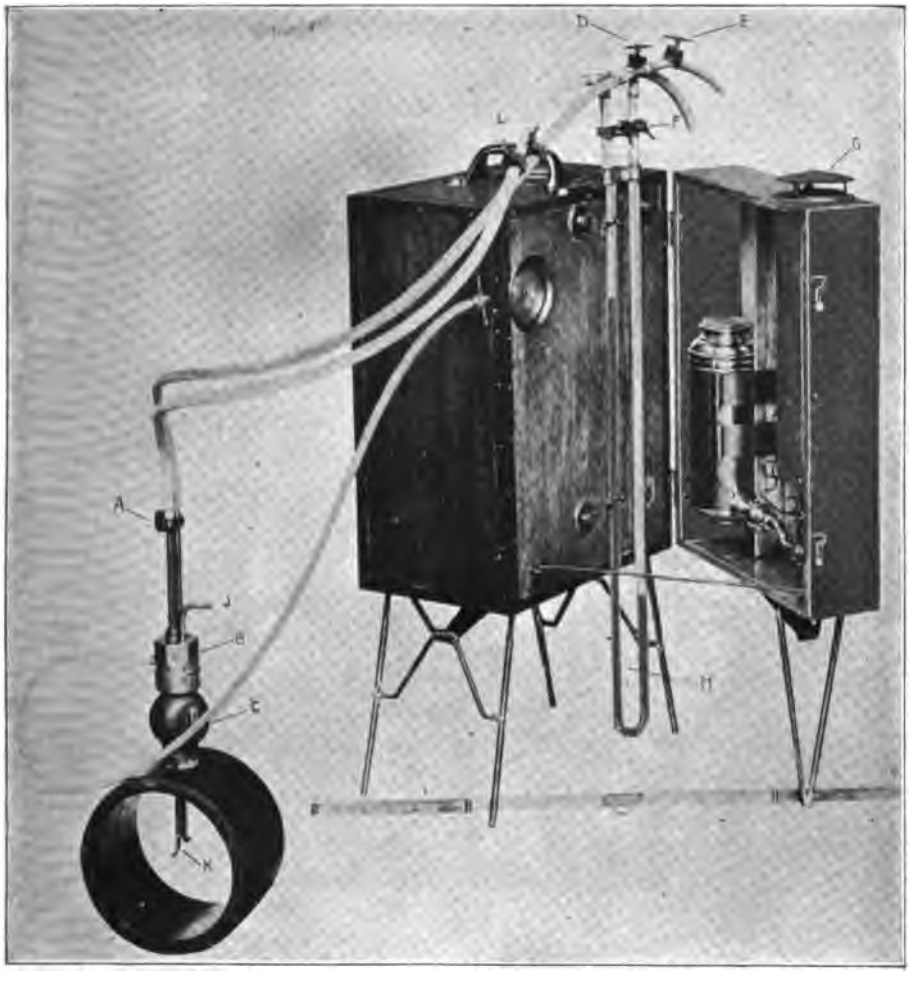

FIG. 5.—THE PHOTO-PITOMETER

The pitometer as described was developed by the writer about ten years ago for use as a waste meter in an investigation at Terre Haute, Indiana. The instrument proved to be accurate and efficient, and has since been adopted on important tests in our largest cities. Its funda-

mental principle was discovered by the French engineer, Pitot, about the year 1732 and later improved by D'Arcy for use in open channels.

The application to water mains under pressure has been developed

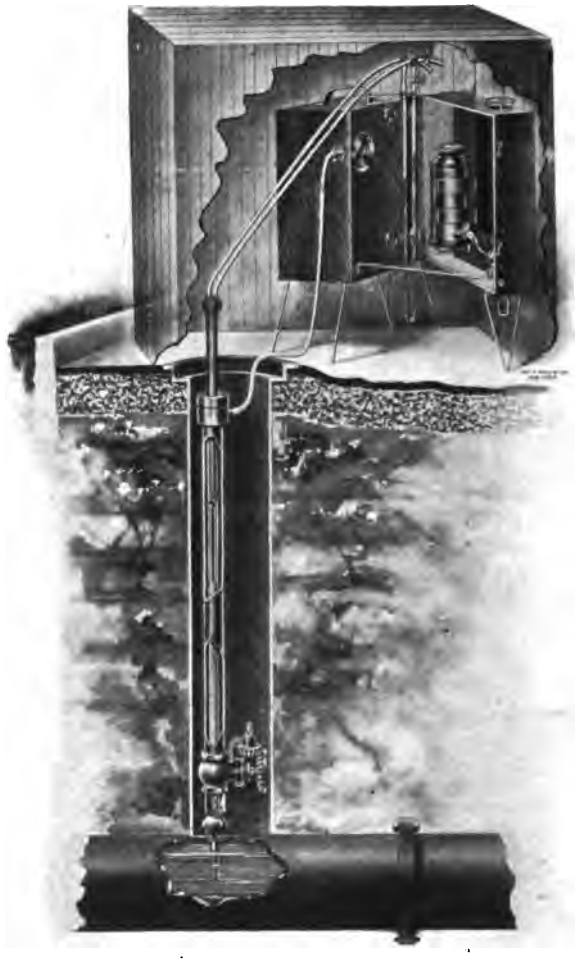

FIG. 6.—THE ROD METER, STREET CONNECTION, AND SHELTER BOX

during recent years, until the Pitot tube may now be classed among the most useful and accurate engineering instruments.

This instrument is primarily a rate meter, depending as it does upon the velocity of water within the main. It does not directly indicate the total discharge in cubic feet in a given time, as with ordinary meters,

but this elimination of the time element is necessary in a waste meter, for by the changes in rate we are able to study the effect of closing valves and service cocks in such an investigation as just described.

The instrument may be described as follows: Two small tubes bent at their lower ends, with carefully formed orifices, are held in a suitable cap, which screws upon a standard 1-inch corporation cock, through which the tubes may readily be introduced into any main and as easily withdrawn. The rod meter is the most recent development of the instrument, by which the slender tubes are enclosed in an oval sheath, which enables the meter to be introduced into the main from the surface of a city street through a "street connection" which is permanently set upon the main. Wherever street connections are set they are always available for use, and by the application of the portable rod meter the flow in the main can at once be ascertained.

FIG. 7.—THE PITOMETER STREET CONNECTION

Heavy cloth insertion rubber tubing connects the orifice tubes with a long glass manometer, or U-tube, and blow-off cocks are provided to remove air from the instrument. The U-tube is half filled with a mixture of carbon tetrachloride and gasoline, having a specific gravity of 1.25, and when in use the water from the pipe fills all the remaining space in the U-tube and connections. The orifices are set to receive the maximum velocity within the main, which is usually near the centre, and is indicated by the deflection in the manometer. This deflection, by virtue of the differential action of the water and the slightly heavier and insoluble liquid, is just four times that due to the actual difference of water head on the orifices produced by the flowing stream. The current impinges directly on one orifice, but the other is turned down

stream, and gives something less than the static head within the main, thus increasing the difference of pressure produced. This difference is then multiplied in the U-tube, the result being that even a low velocity within the pipe produces a readable deflection. Without this effect the Pitot tube would hardly indicate a velocity less than 1 foot per second, while the pitometer is reliable at velocities as low as 6 inches per second. At ordinary velocities the U-tube deflections may run up to 24 inches, and therefore need not be read with any great nicety.

The photo-recorder consists of a portable box in which a drum carrying Velox paper revolves before a fine vertical slit, just in front of which is locked one leg of the U-tube in such a position that the rays of light from an oil lamp will be partly intercepted on their way through the colored liquid in the lower half of the manometer. As the liquid rises and falls with the velocity in the pipe, it will record on the Velox paper a line or band of shade whose ordinates vary according to the well-known formula:

$$V = c\sqrt{2gh},$$

in which h is one-quarter of the U-tube deflection in feet, or half of the recorded ordinate on the paper. A twelve-hour photographic record is 18 inches long and 10 inches high. Autographic horizontal lines are formed by notches in the drum slit, spaced so as to correct for the angularity of the light and enable the true deflection to be readily taken from the diagram at any point.

An autographic record of variation in static pressure is superimposed upon the flow diagram by means of a suitably connected gauge and movable finger, which intercepts the light passing through the U-tube and slot. This pressure record is of great value in the interpretation of any sudden change in the rate of flow, for by its aid we may know whether the observed change in rate is caused by a corresponding variation in pump pressure, as in "direct systems," or by the change in rate of draught within the district under investigation. Thus the detection of waste is facilitated.

The accuracy of the pitometer has been established by many weir tests, and also by calibration in open channels, where the absolute velocities indicated by the instrument were compared with float measurements.

The calibration constant c of the orifices has thus been experimentally determined to be .80 in our formula.

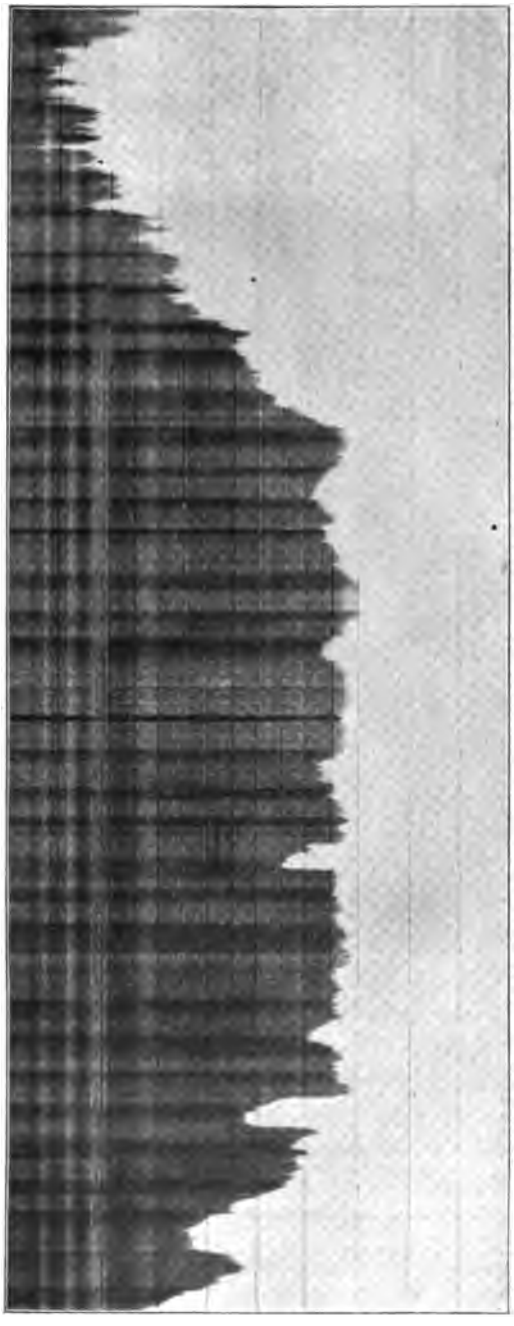

FIG. 8.—A 24-HOUR PHOTO RECORD (REDUCED) OF CONSUMPTION BY A CITY RESIDENCE DISTRICT HAVING A POPULATION OF 46,000

Minimum rate of night consumption is shown to be 1.6 gallons per capita per hour

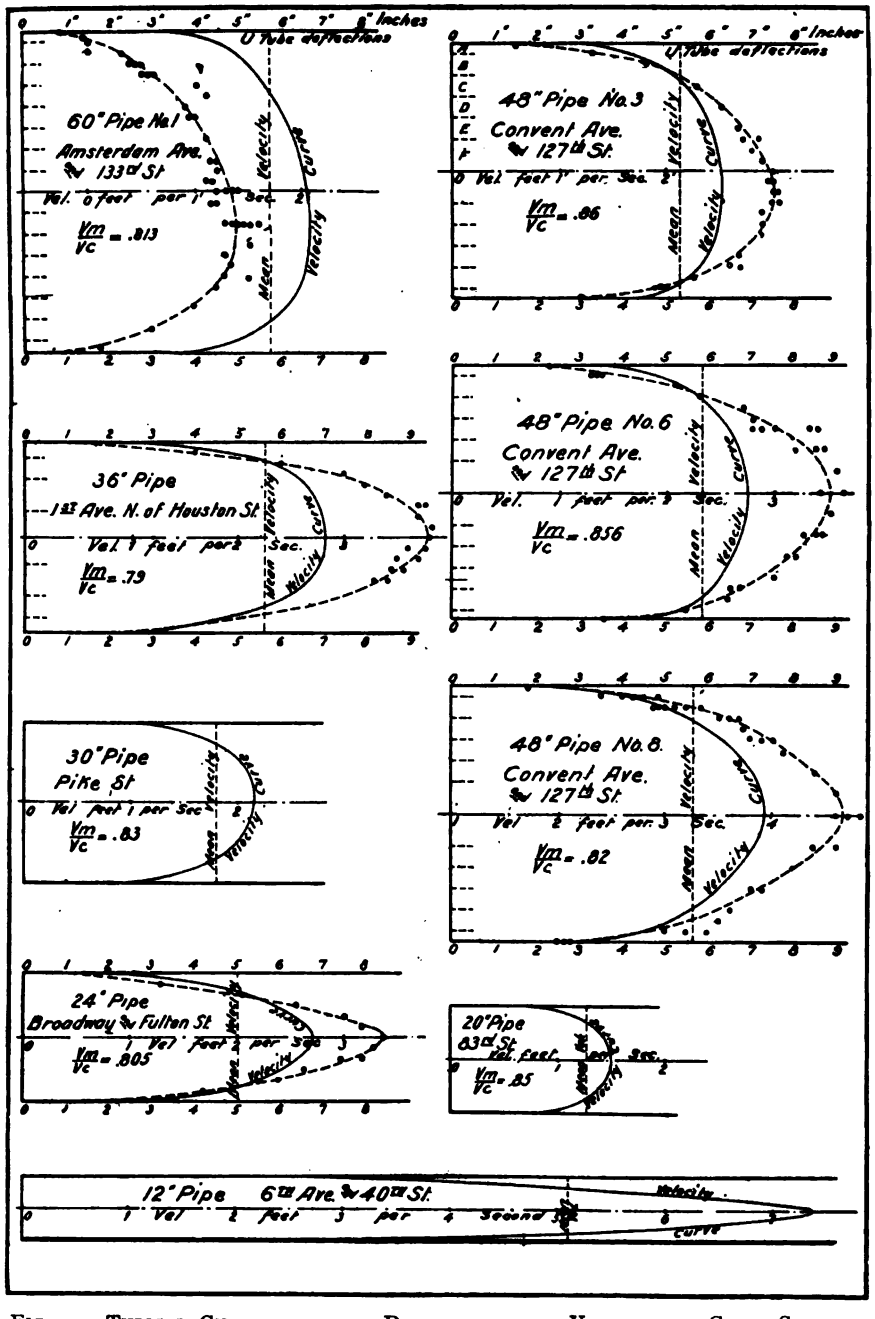

FIG. 9.—TYPICAL CURVES SHOWING DISTRIBUTION OF VELOCITY IN CROSS-SECTION OF PIPE

The full-line curves show velocities; the dotted line curves show the pitometer U-tube deflections

We have, then,

$$V = .8\sqrt{\frac{2gd}{4}} = 3.212\sqrt{d},$$

in which d is the U-tube deflection in feet. The actual velocity of the water is indicated in this way wherever the orifices may be placed within

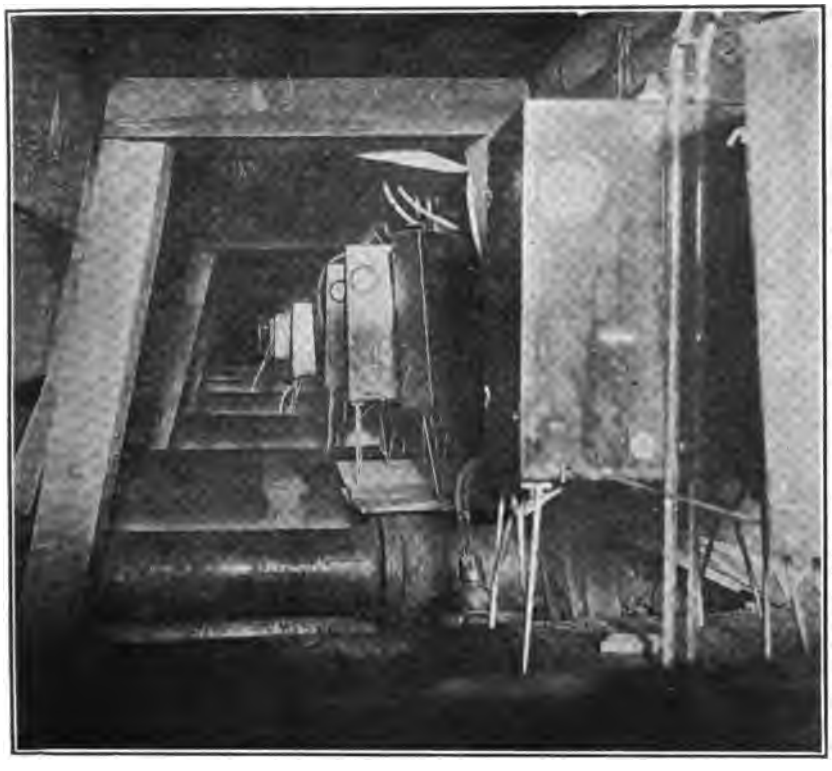

FIG. 10.—PITOMETERS RECORDING THE FLOW OF EIGHT 48-INCH AQUEDUCT MAINS SUPPLYING MANHATTAN, NEW YORK CITY

a pipe, and by completely traversing a given pipe section on one or two diameters the ratio of mean to maximum velocity is computed at some one rate of flow.

This ratio once determined for a given pipe holds good at all velocities. The orifices are permanently set to give the centre or maximum velocity within the pipe, reading off the mean velocity and the discharge from a table prepared for the particular size of pipe and veloc-

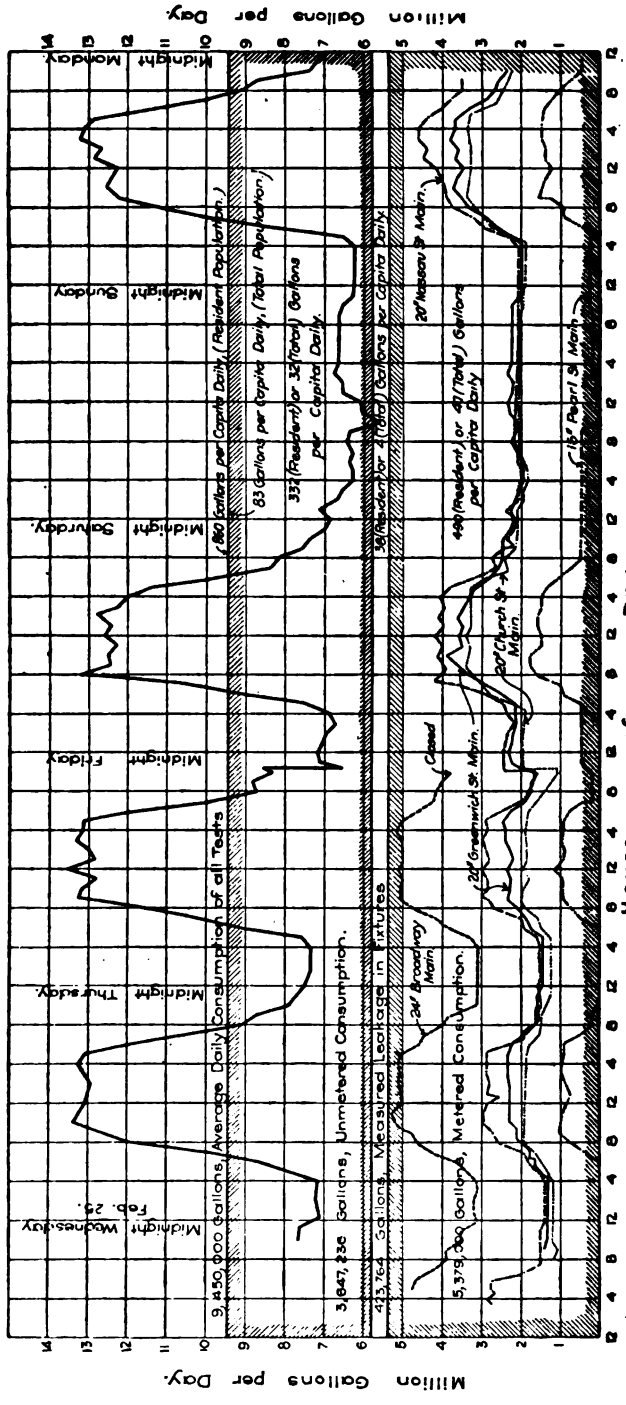

FIG. 11.—THE FINANCIAL DISTRICT OF NEW YORK, IN WHICH PRACTICALLY ALL BUILDINGS ARE METERED

A five-day gauging of supply by pitometers shows that the meters of this section account for but little more than half of the actual supply

ity ratio. This method leaves nothing uncertain. The mean velocity computed from a traverse of a pipe with the pitometer has been checked by careful weir measurement of the flow in pipes from 4 inches to 72 inches in diameter, with close agreement. With careful use, discharge in pipes may be determined by the pitometer within 2 or 3 per cent. of the truth, an accuracy which is highly satisfactory for the solution of practical hydraulic problems.

CONTRIBUTIONS FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE DETERMINATION OF THE ORGANIC NITROGEN IN SEWAGE BY THE KJELDAHL PROCESS

II. STUDIES ON DIRECT NESSLERIZATION

BY LEYLAND WHIPPLE

THE value of a method of analysis, when used in routine work, becomes to a considerable extent a function of the rapidity with which it may be carried out. In no case, perhaps, is this better exemplified than in the estimation of organic nitrogen by the Kjeldahl process, in sanitary water and sewage analysis. This determination, by far the most important, from the viewpoint of interpretation, involves one of the longest procedures, and is consequently not generally employed.

Several attempts have been made to shorten this process by nesslerizing the diluted digestate directly, without distillation. Unless special precautions are taken, however, certain constituents of the digestate are found to react with the Nessler's reagent, producing a turbidity in the presence of which it is not possible to make close comparisons of the color of the nesslerized tube with that of the standard. Of the heretofore published methods, only one, that of Kimberly and Roberts (1906), has been found to be uniformly successful under local conditions, and this method has in our hands failed to yield satisfactory results.

It is the purpose of this paper to present the results of some experiments carried out in this laboratory on direct reading of Kjeldahl digestates, and to give a procedure which has been found entirely successful here and which may be of application elsewhere.

PREVIOUS RESULTS

Direct reading of diluted Kjeldahl digestates has been the subject of investigation both in this country and abroad. Rideal (1901) gives a procedure which consists in neutralizing with an excess of caustic soda, diluting to a definite volume, allowing to settle for a number of

hours, and pipetting off a portion of the clear supernatant liquid for nesslerization.

Phelps (1904), at this laboratory, tried making up the digested sample to volume, taking out the requisite amount, neutralizing and making up to 50 c.c. in the Nessler tube. He found that in about half the cases a turbidity was produced on adding the Nessler reagent.

McGowan (1904) attempted to use a modification of the Rideal method by making *just neutral* with hydrate, and in some cases adding potassium oxalate to precipitate the calcium. He found, also, that in more than half the total number of determinations the tubes were too turbid to read. Furthermore, he pointed out a probable loss of ammonia by adsorption in the precipitate formed. He attributed the turbidity to the insufficient precipitation of the calcium.

As a result of an extended investigation carried out at the Columbus Sewage Testing Station, Kimberly and Roberts (1906) published a modification of the processes of Rideal and McGowan, which consisted in diluting the digestate to 100 c.c., nearly neutralizing with sodium hydrate, cooling, adding a slight excess of hydrate and then 2 c.c. of a 10 per cent. solution of sodium carbonate solution, diluting to a known volume, allowing to settle six hours, and nesslerizing a portion of the clear liquid. This method was the result of a series of investigations into the causes of turbidity, the latter being finally attributed to the presence of calcium and magnesium salts. Kimberly showed that an amount of calcium up to 2.5 mg. per nesslerized tube would not produce turbidity, but that in greater concentrations it would interfere with the process. He used a slight excess of caustic to precipitate the magnesium, and sodium carbonate to precipitate calcium. The long period of settling was necessary in order to remove the slow-forming calcium carbonate.

He states, further, that potassium permanganate cannot be used to complete the digestion, as the manganous sulphate formed will cause turbidity on nesslerizing. The cooling before final neutralization was recommended to avoid the escape of ammonium hydrate from the hot solution. He found it necessary, also, to purify the soda by permanganate, in order to remove iron and organic impurities. In his experiments on the accuracy of the process, he found that adsorption was a negligible factor. In numerous comparative determinations by distillation and direct nesslerization close agreements were obtained.

In an endeavor to obtain a method for the direct reading of Kjeldahl digestates at this laboratory, the method of Kimberly and Roberts was

tried, but failed to yield satisfactory results, it being found impossible to obtain clear tubes upon nesslerization. We have therefore further investigated the causes tending to produce turbidity, and have succeeded in devising a modification of the Rideal method which is successful under conditions found here, and which should be applicable to all sewages except under conditions which will be defined later on in this paper.

Causes of Turbidity in the Tube

The causes of the turbid tube have been variously attributed to the presence of calcium, magnesium, sulphate ions, and manganous salts, resulting from the use of potassium permanganate to complete the digestion.

Kimberly and Roberts have shown that sulphate ions are not one of the disturbing causes. In regard to manganous salts, it is a well-known fact that permanganate is rapidly hydrolyzed and reduced in dilute solutions, either weakly acid or alkaline, and is then precipitated on standing. When used to complete the digestion, the permanganate is at once reduced by the hot acid, and settles out of the diluted digestate as a basic salt. Moreover, should traces of manganous sulphate yet remain in solution, they will be precipitated upon neutralization. Permanganate has been used throughout the present investigation and has never given rise to any cloudiness in the tube.

We have confirmed the conclusion of Kimberly and Roberts that calcium may be present in the tube up to 2.5 mg. without producing turbidity. As an amount of sewage is normally taken which will give a reading of not more than five on the colorimetric standards, corresponding to .05 mg. of nitrogen, it is clear that we cannot have more than fifty parts of calcium to one of nitrogen. That is, in a sewage in which the calcium content is not over fifty times that of the nitrogen, tubes which will give a reading of five or less may be nesslerized directly without any special precautions being taken to remove the calcium. Except in the case of a good sand-filter effluent from a sewage very high in calcium, this ratio will seldom be realized. Even in cases where this ratio is exceeded, it might be advisable to use a less amount of the sample, so as to make the reading about two on the standards. This would increase the allowable ratio of calcium to nitrogen to 125.

Similarly the allowable ratio of magnesium to nitrogen was determined, and found to be so low that the removal of magnesium appears

to be an essential detail. An amount of magnesium in the tube of over .025 mg. will produce either a cloudiness or a considerable deepening of the color of the reagent. To determine the amount of excess hydrate required to effect sufficient precipitation of magnesium salts, a sample was made up containing about 0.12 mg. nitrogen as ammonium chloride, 2.5 mg. magnesium as chloride, and digested with 5 c.c. of sulphuric acid in the usual way, with the addition of permanganate. The digestate was diluted to 250 c.c., and successive portions of 10 c.c. each were neutralized with varying amounts of a 5 per cent. solution of sodium hydrate, starting with an amount just sufficient to neutralize the acid, as determined by a test portion, using phenolphthalein as an indicator. The samples were filtered through washed filters into Nessler tubes, and the filter and precipitate then washed with ammonia free water.

The results of this experiment are shown in the following table:

Tube.	5 per cent. hydrate. c.c.	Reading.	Remark.	Corrected reading.*
1	7.2	. .	Very turbid	. .
2	7.5	. .	Very turbid	. .
3	8.0	About 5.0	Considerably turbid	4.8
4	9.0	5.0	Slightly turbid	4.8
5	10.0	4.8	Clear	4.6
6	12.0	4.9	Clear	4.7
7	15.0	5.0	Very slightly turbid	4.7
8	20.0	About 5.8	Considerably turbid	5.4

* A blank on 10 c.c. of the hydrate gave a reading of 0.2; the figures in this column have had this correction applied.

This indicates that after neutralization an excess of hydrate must be added equivalent to 1.5 grams per 100 c.c. of the diluted digestate, in order to effect a satisfactory removal of the magnesium. Furthermore, it is indicated, and we have further confirmed the fact, that the reading is not appreciably affected by an excess of hydrate unless in sufficient amount to itself cause turbidity. This amount has been found to be about 0.35 gram per 50 c.c. Nessler tube.

The addition of copper sulphate to hasten the digestion has no effect on the final result, as the copper is entirely removed by the hydrate.

It appears, therefore, that magnesium salts are one of the principal causes of turbid Nessler tubes; that the magnesium can be satisfactorily removed by an excess of sodium hydrate; and that this necessary excess is not in itself sufficient to produce turbidity.

Method

The detailed procedure which has been in use at this laboratory for the past three months is as follows:

Reagents.—The same as those used in ordinary Kjeldahl determinations of organic nitrogen, with the addition of a 5 per cent. solution of potassium or sodium hydrate.

Procedure.—Fifty c.c. of the sample (or a greater or less amount, according to the nitrogen content) are digested with 5 c.c. of concentrated sulphuric acid, nitrogen free, and a small amount of copper sulphate until colorless. The digestion is completed by the addition of a few small crystals of permanganate to the hot acid. After cooling, the digestate is diluted to 250 c.c., mixed, and a portion (say 25 c.c.) is pipetted out, mixed with an equal portion of 5 per cent. sodium hydrate solution, and filtered through a filter paper which has been washed previously with 100 c.c. or so of ammonia free water to remove traces of ammonia. Twenty c.c. of the filtrate are pipetted into a Nessler tube, made up to 50 c.c. with best water, mixed by pouring from one tube to another, nesslerized, and read after ten minutes. A blank should be run on the entire process, and the result subtracted from the reading.

Discussion

This method has been in use in this laboratory for the past three months, and has given uniformly satisfactory results. In no case have we experienced any difficulty in getting a clear tube of the correct color to match the standards, even in tubes reading as high as seven or eight on the standards, corresponding to .07 and .08 mg. of nitrogen in the tube. In practice, however, readings of over five are discarded and new dilutions made, the rapidity of the process making it readily possible to introduce this desirable procedure.

In all these experiments, and in our regular work, the ordinary purified caustic soda in sticks has been used, preliminary purification having been found unnecessary.

Accuracy

Duplicate determinations made on the same digestate by distillation and by the direct method show a very close agreement. The following analyses were made, on three different dates, on sewages and effluents of trickling filters:

Total Kjeldahl Nitrogen

Parts per Million

Sample.	Distilled.	Direct.
Sewage	19.5	19.5
Sewage filtered	18.0	17.5
Sewage	20.0	19.5
Sewage filtered	18.0	18.0
Sewage	23.5	23.5
Sewage filtered	17.5	17.5
Effluent	15.0	15.0
Effluent filtered	9.5	9.0
Effluent	14.5	14.5
Effluent filtered	12.0	12.0
Effluent	13.5	Lost
Effluent filtered	12.5	12.5
Settled effluent	12.5	12.0
Settled effluent filtered	11.0	10.5
Settled effluent	12.0	11.5
Settled effluent filtered	11.5	11.0
Settled effluent	14.5	15.0
Settled effluent filtered	13.0	13.0

The uniformity of these figures shows the loss during filtration or by adsorption in the precipitate to be negligible.

This process commends itself for the following reasons:

(1) The great saving of time over the distillation process.

(2) The less bulky and bothersome apparatus required.

(3) An accuracy fully equal to that of the distillation method.

(4) The saving in time over all previously published direct methods, the immediate filtration taking the place of the long period of settling heretofore employed. The possible loss of ammonia in the filtration has been shown to be negligible.

(5) More satisfactory results locally than previously published direct methods, and greater probability of its being applicable under a wide range of conditions.

Summary

(1) The direct nesslerization of Kjeldahl digestates is greatly to be desired, but unless special precautions are taken such a procedure will result in a precipitation of the Nessler's reagent by certain constituents of the digestate.

(2) The present study indicates that under ordinary conditions no trouble will be experienced on account of calcium, no special treatment for its removal being necessary unless the calcium content of the sewage is greater than fifty times the nitrogen content.

(3) Magnesium, on the other hand, even in small amounts, will cause a turbidity in the tube and render a correct reading impossible.

(4) Magnesium can be satisfactorily removed, but to do this requires an excess of sodium hydrate equivalent to a concentration of 1.5 grams per 100 c.c.

(5) The excess of sodium hydrate necessary to remove the magnesium is not great enough to interfere with the reading. In fact, this reading is not appreciably affected unless the concentration of hydrate is such as itself to produce turbidity, or about 0.35 gram per 50 c.c. Nessler tube.

(6) It is not at all certain that the turbid tube results solely from the presence of magnesium. It has been determined, however, that under the conditions required for the removal of magnesium any other deleterious constituent is also eliminated.

(7) A process is recommended whereby all disturbing constituents can be removed and the Kjeldahl digestate nesslerized directly. By filtering the neutralized digestate a saving of several hours can be effected over heretofore proposed methods.

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RECENT RESULTS OF TERRESTRIAL MAGNETIC OBSERVATIONS

By L. A. BAUER

Read March 28, 1907

In 1838 Sir Edward Sabine, who during the first half of the last century may justly be said to have taken the most active part in mapping out the distribution of the Earth's magnetic forces, concluded one of his reports with the following words: "Viewed in itself and its various relations, the magnetism of the Earth cannot be counted less than one of the most important branches of the physical history of the planet we inhabit; and we may feel quite assured that the completion of our knowledge of its distribution on the surface of the Earth would be regarded by our contemporaries and by posterity as a fitting enterprise of a maritime people and a worthy achievement of a nation which has ever sought to rank foremost in every arduous and honorable undertaking." Lord Kelvin, then Sir William Thomson, said in his presidential address before the British Association meeting of 1871, referring to Sabine's conclusion of his magnetic labors as embodied in his magnetic charts of the world for the period 1840 to 1845: "Science will be provided with a key which must powerfully conduce to the ultimate opening up of one of the most refractory enigmas of cosmical physics, the cause of terrestrial magnetism."

Sabine says in another report, in 1854, after the discussion of the results of the magnetic observations made under his direction at the British Colonial Observatories during the period 1840 to 1850: "We have hitherto known magnetism only as a telluric force of much less apparent simplicity than gravity, and greatly requiring a key to enable us to apprehend its laws as well as its purposes in the general economy of nature. But if, as we appear to have reason to believe, we are to view the magnetism not only as *a telluric but also as a cosmical force,* the interest and importance of our inquiries regarding it must undoubtedly be viewed as greatly augmented."

If I may be permitted one more quotation, Maxwell, in his treatise on electricity and magnetism, remarks that "the field of investigation into which we are introduced by the study of terrestrial magnetism is as profound as it is extensive." "What cause," inquires he, "whether exterior to the Earth or in its inner depths, produces such enormous changes in the Earth's magnetism that its magnetic poles move slowly from one part of the globe to another? When we consider that the intensity of the magnetization of the great globe of the Earth is quite comparable with that which we produce with much difficulty in our steel magnets, these immense changes in so large a body force us to conclude that we are not yet acquainted with one of the most powerful agents in nature, the scene of whose activity lies in those inner depths of the Earth, to the knowledge of which we have so few means of access."

These four pertinent quotations will serve to point out admirably and briefly the main lines of research in terrestrial magnetism, viz.:

1. The distribution of the Earth's magnetism prevailing at any specified time, involving the mapping out of the so-called permanent magnetic field of the Earth.

2. The determination of the slow but steadily progressive changes of the Earth's magnetism, the so-called secular changes, requiring many centuries for their complete development. As the result of these changes, it is necessary to issue new magnetic charts, even for the practical purposes of navigation, at intervals certainly not over ten years apart, and preferably not over five years. It is this feature which differentiates the phenomena of the Earth's magnetism from those of other branches of geophysics. Thus, as Herschel aptly put it, "The tides and currents of the ocean—the general course of winds—the affections of climate, etc., remain for thousands of years appreciably constant, but a few years suffice to alter materially and the lapse of half a century or a century to remodel completely the Earth's magnetic forces."

3. The comparatively rapidly occurring variations and fluctuations of the Earth's magnetism, recorded usually by photographic means at magnetic observatories, such as the daily variation, the annual variation, magnetic perturbations, etc. It is by means of this class of magnetic phenomena that we are brought into sympathetic touch with influences coming to us both from the regions beyond the Earth as well as from the Earth's interior.

Manifestly, in the brief space of an hour it will be utterly impossible

to present completely the recent results of magnetic research along these three main lines of inquiry. Instead, we shall have to confine ourselves chiefly to the first two, and even here content ourselves with certain typical cases showing the general progress made.

In view of the establishment by the Carnegie Institution of Washington of a Department of Research in Terrestrial Magnetism, whose special function is to complete a general magnetic survey of the globe within a period of about fifteen years, this country at present occupies the same prominent position with reference to the problems of the distribution of the Earth's magnetism and its secular variation that England did in the last century during Sabine's time. However, even before this work of the Carnegie Institution was established, it was generally conceded that in no other country were these problems receiving the continuous attention paid to them in the United States. This was in not a little measure due to the fact that in our country, owing to the extensive use of the compass in land surveys, especially in the earlier ones, the investigation of these problems was of great practical importance, besides being of great theoretic interest.

Thus, almost at the very beginning of the work of the United States Coast and Geodetic Survey, it became necessary, on account of the numerous inquiries received from all parts of the country as to the direction of the compass needle and especially as to the changes which the compass direction had undergone during a certain interval of time, to include magnetic observations in its scope. So we find recorded for various places in the New England States determinations of the magnetic declination by the first superintendent, Hassler himself. And when Bache succeeded Hassler as superintendent, magnetic observations were definitely recognized as forming an integral part of the work of the Survey. Not only were determinations of the magnetic declination systematically undertaken at various places, but also the other two elements of magnetic measurements were included, viz., the dip of the magnetic needle and the intensity of the Earth's magnetic force. Bache had previously made a magnetic survey of Pennsylvania, in which enterprise he was not followed by other states until in quite recent years by the magnetic surveys of Missouri, New Jersey, Maryland, North Carolina, and Louisiana.

The magnetic survey of the United States thus fairly started under Bache was steadily prosecuted without interruption over the entire country and Alaska, under the main direction of the late chief of the

Computing Division, Charles A. Schott, whose exhaustive compilation and discussion of magnetic data for the determination of secular variation were unequaled by the work of any other magnetician during his period. Owing to the rather limited appropriations, however, it was not possible to make as rapid progress as was requisite to meet both practical and scientific needs. In the meanwhile, Professor William Bullock Clark, State Geologist of Maryland, perceiving the desirability of more rapid and more detailed work than could be undertaken with its funds by the Coast and Geodetic Survey, organized a magnetic survey of Maryland under my direction; this work was undertaken chiefly during the summers of 1896, 1897, and 1898.

It must be considered a fortunate circumstance for the development of magnetic research in this country that Dr. Henry S. Pritchett was at this time the superintendent of the Coast and Geodetic Survey. He was quick to perceive that the methods and plan of work followed in the Maryland survey could profitably be extended to embrace the entire country, and so he undertook a complete reorganization of the magnetic survey of the United States, creating a special division known as the "Division of Terrestrial Magnetism," the magnetic work previously, as above stated, having been under the charge of the chief of the Computing Division. At his request I prepared a plan according to which a magnetic survey of the United States might be undertaken in such a way that a general magnetic survey would be completed within a period of about ten years, after which the further work would consist in filling in details where local disturbances manifested themselves and in repeating observations at certain well-selected stations at intervals of about five years, with the aid of which a control would be had upon the secular changes, making it thus possible always to keep magnetic maps up to date. This plan called for an annual expenditure for field expenses of the magnetic survey and the magnetic observatories established in connection therewith of $25,000—about ten times the previous annual appropriations.

Dr. Pritchett, having succeeded in securing from Congress the increased appropriation, invited me to take charge of the work. Beginning, therefore, with July 1, 1899, a magnetic survey of the United States was prosecuted with means sufficient to occupy annually about four hundred stations, at which the three magnetic elements, declination, dip, and intensity, were determined, and to establish magnetic observatories, at present five in number, where the Earth's magnetic vari-

ations are being continuously recorded. These observatories are situated at Cheltenham, Maryland, the principal observatory, at Porto Rico, Baldwin, Kansas, Sitka, Alaska, and near Honolulu, Hawaiian Islands.

Furthermore, in 1903 another desire of Dr. Pritchett's was realized through the zealous interest of his successor as superintendent, Mr. O. H. Tittmann, viz., the incorporation of magnetic work at sea as one of the regular duties of the vessels of the survey in their passages between United States ports, thus securing magnetic data—and again the three elements—on the oceans bordering upon our coasts. Having secured the necessary instruments, I accompanied the Coast Survey steamer *Blake,* under the command of Mr. R. L. Faris, my successor in charge of the magnetic work of the Coast and Geodetic Survey, on her cruise from Baltimore to Porto Rico. Our work was so successful that upon arrival at San Juan we were enabled to cable Superintendent Tittmann, "Marine magnetics successful; observations secured daily." After the preliminary work on the *Blake,* other vessels were fitted out with magnetic instruments, viz., the *Bache,* the *Patterson,* and the *Explorer,* so that now the annual summaries of magnetic results also regularly include some obtained at sea, besides those on land.

These, in brief, are the general lines along which the expansion in the magnetic work of the Coast and Geodetic Survey was made in 1899.

Our first slide exhibits the status of the magnetic survey of the United States from the beginning—about 1840—up to June 30, 1899, hence up to the reorganization. The round dots represent the points of observation at which in general the three magnetic elements had been observed and at which, in a number of cases, these observations had been repeated at various intervals, beginning with about 1840. It will be seen that the work was mainly in the states bordering our coasts, the stations in the inland states being necessarily comparatively few in number and designed primarily as "repeat" stations for determining the secular changes over the entire country.

The next slide shows the status of the magnetic survey up to December 31, 1906, *i. e.,* up to about the time of my relinquishment of the charge of the work in order to devote myself to the still greater task—a magnetic survey of the globe. From this slide will be seen the large expansion that resulted within the period of seven years, 1899 to 1906. We now find every state fairly well covered, there being on the average one station to about 800 square miles, *i. e.,* in general there are values of the three magnetic elements at intervals of about 30 miles,

or, say, about one station per county in each state. This makes about 3,500 fairly uniformly distributed points over the United States at which the magnetic declination, the magnetic dip, and the intensity of the Earth's magnetic force have been determined by approved methods and with instruments carefully intercompared and standardized. In consequence it may be said that, considering the area involved—nearly equal to that of Europe, or about one-sixteenth of the entire land area of the globe—the United States of North America possesses the most complete and homogeneous magnetic survey of any country, and that the phenomena of secular variation have received more careful attention here than in any other country. While some of the European countries possess magnetic surveys of greater detail, with a much denser distribution of stations—as, for example, that of Great Britain, one station to every 139 square miles, and that of Holland, one station to about every 40 square miles—these surveys, having been undertaken with funds specially provided by certain organizations and not in general conducted under official or governmental auspices, could not be as systematically and continuously prosecuted as is the case with our own magnetic survey; they hence, necessarily, relate to various epochs. In the course of time we may hope to reach a density of distribution equal to that of certain European countries. In this connection it will not be amiss to point out that for certain regions of the United States this desired goal has already been reached, *e. g.*, the magnetic survey of Maryland embraced on the average one station to 100 square miles—hence occupying an intermediate position between those of Holland and Great Britain. Before passing to the next slide permit me to call your attention to the oceanic stations at which the magnetic elements have been determined in recent years by the vessels of the Coast and Geodetic Survey, as has already been stated.

Now to exhibit some of the results of this magnetic survey work. On the next slide we have shown us the lines of equal magnetic declination for the year 1902. In the construction of this chart it was necessary, owing to the insufficiency of the data when its construction was undertaken (about 1901), to make use of results obtained from other than governmental sources. The auxiliary data, consisting almost entirely of surveyors' results, did not, in general, possess the requisite degree of accuracy to permit full reliance being put upon them, making it hence unwise to do more than to draw general or regular lines of equal magnetic declination. Wherever, therefore, such regular lines appear in

the present slide, it may be safely concluded that the data were either not sufficiently numerous or not sufficiently reliable to warrant showing irregularities.

In the following slide (Fig. 1) a considerably different appearance is presented. Here we have the lines of equal magnetic declination for January 1, 1905, as based upon all the reliable magnetic observations secured up to about August 1, 1906, cutting out this time entirely sur-

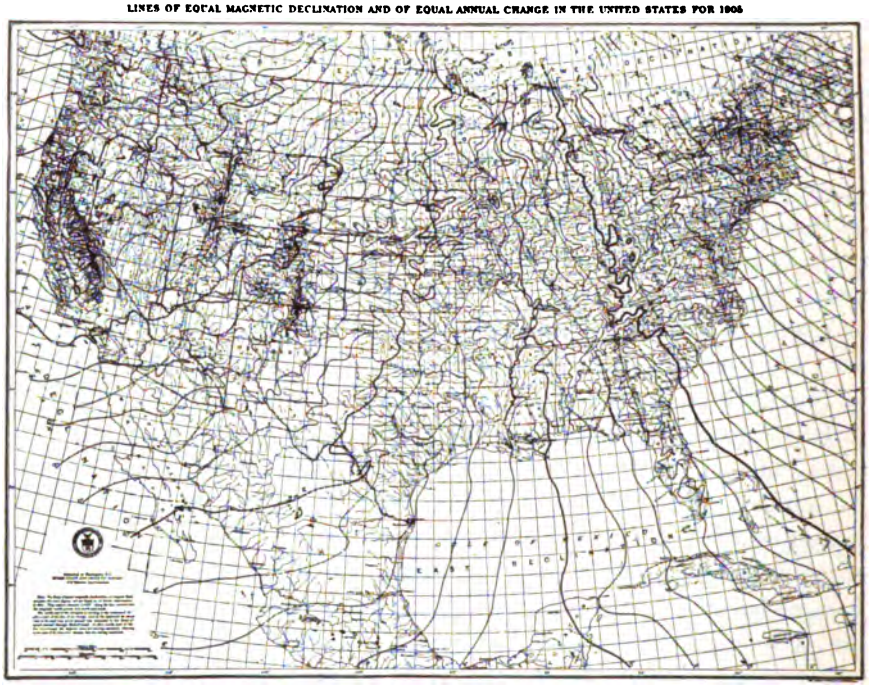


FIG. 1.—LINES OF EQUAL MAGNETIC DECLINATION AND OF EQUAL ANNUAL CHANGE IN THE UNITED STATES FOR JANUARY 1, 1905

veyors' data, the number and distribution of the reliable observations making this for the first time possible. In round numbers, as already said, the present chart depends upon the magnetic observations at about 3,500 fairly uniformly distributed points. What will impress one most, doubtless, is the exceedingly large number of twists and turns shown by the lines. In this respect the present chart differs materially from all previous ones issued for this country. We no longer have gracefully flowing or mathematical curves (as shown, for example, by the isogonic charts of forty years ago), but instead exceedingly irregular ones. This

is a sufficient proof that the present chart represents more closely the actual facts of nature than any previous one, for it is a well-known fact that the more numerous the reliable observations are, the more devious become the lines of equal magnetic values. In fact, we are being taught more and more that the irregularities are not the *abnormal* features, but, on the contrary, are the *normal* ones.

Regularities in the distribution of the Earth's magnetism over land areas do not appear to exist, at least not for any extended areas. Thus for states in which, judging merely from the superficial geological formations, no great irregularities in the magnetic distribution should occur, there they nevertheless do manifest themselves. The time will not permit going into all of these details and pointing out the precise relationship between local magnetic disturbances and certain physiographic or geological features. I can only point out a few typical cases. The agonic line, or the line of no magnetic declination, along which the compass needle points "true to the North Pole," is one of interest in its passage through the states. It will be noticed that it passes through Ohio somewhat to the west of Columbus and through Columbia, South Carolina. Hence, Columbus, Ohio, and Columbia, South Carolina, will serve to fix in our minds the approximate direction of this line at the present time.

From the figure it will also be seen that for the first time it was possible to project the lines over the oceanic areas immediately beyond our coasts. Here, as is to be expected, the lines appear more regular. Furthermore, with the addition of data acquired by the Carnegie Institution in Canada and Mexico since the construction of this chart, it has become possible in a forthcoming second edition embracing all data up to January 1, 1907, to extend the lines up to the forty-ninth parallel across the entire continent, as also to perfect the lines over Mexico, which had to be drawn more or less tentatively, owing to the paucity of the available material. There are likewise in preparation similar charts of the lines of equal magnetic dip and of equal intensity. When these have been completed, it will be worth while to undertake an analysis of the irregularities shown in the distribution and their correlation with geological formations, etc.

Not only, however, does the present chart represent a vast improvement upon our previous one, but also our knowledge of the secular changes has reached a stage of perfection not hitherto attained. Owing to some marked peculiarities exhibited by this phenomenon during recent

years in the United States, on account of which it was found unsafe to make predictions of the probable direction of the compass at various places for even such a comparatively brief period as five years, it became urgent to repeat the observations at more points throughout the United States and at closer intervals than was heretofore believed necessary. Thus, for example, in California the indications about 1885 were, that the compass, which pointed east of north, had reached its maximum easterly value, so that shortly thereafter it would begin to diminish, somewhat slowly at first and then at an increased rate. On the contrary, however, all recent observations have proven that easterly declination, instead of *decreasing*, since about 1890 has steadily *increased*. The present rate of increase is about 3′.5 per year, or 1° in about seventeen years. So again in Louisiana, where this reversal of the secular change was first detected, it was believed until but a few years ago that east declination was diminishing; instead, however, it was found that it had been steadily increasing for some time. It would appear as though the maximum which it was thought occurred in California between 1880 and 1890 was not a principal one, but a secondary one.

On the other hand, in most of the Atlantic States where we have west declination the values are likewise increasing, the annual rate of increase at present being for Massachusetts about 3′ to 3′.5. The present indications are that before many decades west declination will pass through a maximum in the New England States. This phase, according to recent observations by the Carnegie Institution, having already set in in Labrador and Newfoundland, is steadily moving southwestward. Possibly the briefest statement will be that given on the chart itself, viz., that, owing to the secular change of the Earth's magnetism, "the north end of the compass is moving at present to the westward for all places east of the line of no annual change, and to the eastward for places west of said line, *i. e.*, east of the line of no change the isogonic lines are moving westward, whereas to the west of this line they are moving eastward."

Since the line of no annual change does not coincide with the agonic line, we must distinguish three regions of secular changes in the United States. (1) In the region east of the agonic line or the line of no magnetic declination, where west declination prevails throughout, the declination is increasing from about 2′ to 4′ per annum, the amount in general increasing with the distance from the agonic line until the New England States are reached, where the maximum change

occurs; thence progressing farther northeastward the annual change decreases until we approach the region, before indicated, where west declination is passing through the maximum westerly value.

(2) In the region between the agonic line and the line of no annual change, passing, as will be seen, through Minnesota and Alabama in a direction practically parallel to the agonic line, the magnetic declination (east throughout this region) is decreasing at the rate of 0 to 2′ per annum.

(3) Finally, in the region west of the line of no annual change, embracing over two-thirds of the United States, the magnetic declination, being east throughout, is increasing at the rate of 0 to 4′ per annum, the maximum value being along the Pacific coast.

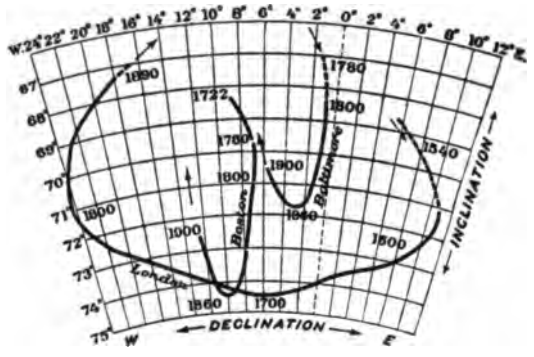


FIG. 2.—CURVES SHOWING SECULAR CHANGE IN MAGNETIC DECLINATION AND DIP AT LONDON, BOSTON AND BALTIMORE

We have indications that in the southern part of Mexico and Central America east declination is decreasing, whereas in the northern part of Mexico it is increasing. In Porto Rico, west declination is increasing at about 7′ per annum, or 1° in nine years.

The effect of the present secular changes in the United States whereby, as we have seen, the isogonic lines are being shifted from both coasts towards some line passing through Minnesota and Alabama—the line of no annual change—considered along with the equally well-known changes in dip and intensity, implies that the magnetic North Pole has moved during the past twenty years mainly southward and somewhat westward, the latter component of motion, however, being greatly subordinate to the southerly one.

In the next slide (Fig. 2) curves are exhibited which show the

secular changes both in the magnetic declination and in the dip at London, Boston, and Baltimore. These are the curves which would be described by the north end of a magnetic needle so suspended as to respond not only to changes in the magnetic declination, but also in the magnetic dip; the observer watching the movement is supposed to be standing at the center of suspension and looking towards the north end. This diagram serves to illustrate several of the interesting and at the same time most perplexing phenomena exhibited by the secular variation. In the first place, a glance suffices to show that, while the three curves are drawn to the same scale, the areas embraced by Boston and Baltimore are considerably smaller than that of the London curve. In England the secular changes of the compass needle can be followed from about 1540 to the present time, or over three and one-half centuries; this is, in fact, one of the longest periods in which these changes can be followed. It is seen that even here the curve is not yet closed and it is an interesting question whether it will close in a simple manner or whether before doing so it will not pass through a loop somewhat comparable with the curves shown by Boston and Baltimore—there being, in fact, indications of such loops—or whether, indeed, it will ever close exactly. In my own opinion, as based upon a variety of investigations, no exact closure will ever take place, that is to say, a freely suspended needle will doubtless never reoccupy in space the same position assumed at some previous epoch.

It is seen that the London curve passed through a period of maximum east declination of about 11° towards the end of the sixteenth century; that the compass pointed duly north and south about 1660; next, the dip had a maximum value of about 74°.5 in 1700, after which it steadily decreased, this decrease still continuing. The compass passed through another maximum, this time of west declination, somewhat over 24°, in the early part of the nineteenth century. Thus during the interval of about 1580 to 1820 the compass direction at London changed from 11° east to 24° west, or 35° in 240 years. Investigations have shown it would be rash to assume that this interval from turning point to turning point is one-half of the total secular variation period. In this country the intervals between two turning points are considerably less than that shown by the London curve, approximately, on the average, about one-half. Again the changes in the magnetic declination, as thus far witnessed in this country during the past two centuries, are considerably less than those experienced at London. In passing, permit me to

call your attention to a matter of historical interest as shown by the Boston curve, which, as is seen, begins about 1722. For this place, namely, we have the earliest value of the magnetic dip in this country, though values of the magnetic declination reach back to the early part of the seventeenth century. This value of the dip at Boston was due to the enterprise of William Whiston, who is chiefly known for his translation of Josephus. Whiston was anxious to capture the prize offered by the British Parliament for the discovery of an easy method for determining the longitude at sea, and believing that this problem could be solved by means of magnetic observations, especially of dip, he supplied various captains of vessels with dip circles. And thus it happened that Captain Othniel Beal made the first determination of the magnetic dip at Boston. Whiston himself made a large number of dip observations as well as of relative intensity in the southern part of England, this work constituting, in fact, the earliest land magnetic survey.

It will be noted that all three curves progress throughout their course in a clockwise direction, and this fact has been found to prevail in general over the entire Earth. Dr. van Bemmelen, with the aid of carefully compiled observations as obtained from the log-books of early voyages, found that the magnetic North Pole during the past three centuries has followed a similar course.

And while speaking of the magnetic North Pole, let us not forget Amundsen's great achievement. Amundsen is at present about thirty-five years of age and extremely modest as to what he has accomplished. You will doubtless recall that the first determination of the position of this pole was made by Captain James Clark Ross, who in June, 1831, found that on Boothia Felix, in latitude 70° 5′.3 north and in longitude 96° 45′.8 west of Greenwich, the dip of the magnetic needle was 89° 59′.5. Now the chief merit of Amundsen's work is not simply that he has found the point again where the dip needle stands practically vertical, but that he made a complete magnetic survey of the entire region involved, and furthermore operated self-registering magnetic instruments in a nonmagnetic hut for a period of nearly two years. It will thus be possible to determine more precisely than was done by Ross the exact position of the Pole and to eliminate the possibility that any one point where the dip needle was observed standing vertical might be locally disturbed. There are, in fact, a number of points on the Earth where, owing to local disturbances, the dip needle stands vertical, the compass direction converges from all sides, and where the force acting upon the

same practically vanishes. Thus, for example, I found such a point, in the fall of 1900, on Douglass Island, near Juneau, Alaska, the local attraction resulting from this local magnetic pole being sufficient to affect compasses on board vessels passing through the Gastineaux Channel, a mile and one-half from shore by about a point (11°). In Southern Russia exists a similar place, where the vertical magnetic force is even greater than at the true North Magnetic Pole.

From the magnetic survey of the United States, we are led naturally to a consideration of the magnetic survey of contiguous territory, viz., that of the Pacific Ocean, now in progress under the auspices of the Carnegie Institution of Washington. An exhaustive discussion of all the magnetic data at present available from over the entire Earth showed that no material progress could be expected in the solution of some of the greater problems of the Earth's magnetism, such, for example, as were referred to in the quotations at the beginning of this paper, until we possess a magnetic survey of the globe which will not only embrace the land areas but the ocean areas as well, and will be based upon strictly homogeneous material throughout. A complete and unequivocal solution of the problem of the precise distribution of the Earth's magnetism requires, furthermore, observations in the vertical direction—in ocean depths and in atmospheric regions.

Thus it was found that in spite of the large amount of most admirable magnetic work done during the latter half of the past century by various eminent investigators, this work was practically all confined to the land areas, and since the land area is exceeded nearly three times by the oceanic area, and since, furthermore, as we have already seen in the case of the United States, the land observations are almost invariably "disturbed," it can readily be seen that deductions applying to the entire Earth, based practically upon land data, are more or less unsafe. As far as the determination of the general magnetic constants and of the general facts as pertaining to the magnetism of the entire Earth, no material advance was made during the period stated. Thus the magnetic maps for the period of about 1880 or 1885 represented no very great improvement over those of Sabine of 1840 to 1845, owing chiefly to the lack of data on the oceans. In certain regions, owing to defective knowledge of secular changes, the later maps were not even as good as the earlier ones. This will be made clear by the next slide, which shows the condition of oceanic magnetic work up to the time of the

work of the Carnegie Institution. Thus, *e. g.*, practically all of the work in the southern oceans was done during the period of the Sabine charts by the expeditions of the *Erebus, Terror,* and *Pagoda,* these vessels being the first ones fully equipped with magnetic instruments permitting the determination of the three elements, magnetic declination, dip, and intensity. It is only recently, *i. e.*, since the appearance of the latest magnetic charts of the last century, that additional material in these regions was obtained by the various Antarctic expeditions.

The *Novara,* an Austrian frigate, obtained a series of declination observations in 1857-1860 which were likewise available to Sabine when he constructed his charts.

The next expeditions equipped for general oceanic magnetic work were those of the *Challenger,* 1872 to 1876, and the *Gazelle* (a German vessel), 1874 to 1876. For the Pacific Ocean it will be noted that the *Challenger* obtained magnetic observations along but a single line passing from Valparaiso to Tahiti, the Hawaiian Islands, and Yokohama. The present magnetic maps for this part of the Earth have had to be based, therefore, almost entirely upon the observations obtained along this one line—brought up to date, furthermore, with more or less conjectural values of the secular changes—upon the observations made on islands and coasts (both of which are in general magnetically disturbed), and upon those obtained occasionally from vessels.

It will be seen that for the eastern part of the Atlantic Ocean the available material is more abundant, especially owing to the acquisitions from the recent Antarctic expeditions.

Passing to our own coasts, it will be seen that the vessels of the Coast and Geodetic Survey since 1903 have already contributed materially to our information.

In 1905 the Department of Research in Terrestrial Magnetism of the Carnegie Institution of Washington was authorized to undertake a magnetic survey of the Pacific Ocean, and the necessary funds were allotted. After considerable advertisement, the brig *Galilee,* a wooden sailing vessel of about 600 tons, built in 1891 and engaged in freighting in the Pacific Ocean, was chartered for the purpose. The principal changes required to adapt her to the work to be undertaken were the substitution of the steel rigging by hemp, the replacing as far as possible of the iron in the blocks and tackle by nonmagnetic metal, and the building of a special observing bridge running fore and aft between the masts and about 15 feet above the deck. The instruments mounted

on this bridge were on the average about 25 to 30 feet from the remaining masses of iron, consisting chiefly of the iron bolts in the sides of the vessel.

While, then, it was not possible to convert this vessel completely into a nonmagnetic one, as would have been desirable, the changes made resulted in reducing the corrections due to the disturbing influence of the iron to such an extent that the so-called ship's "magnetic constants" turned out to be smaller for this vessel, on the average, than those of

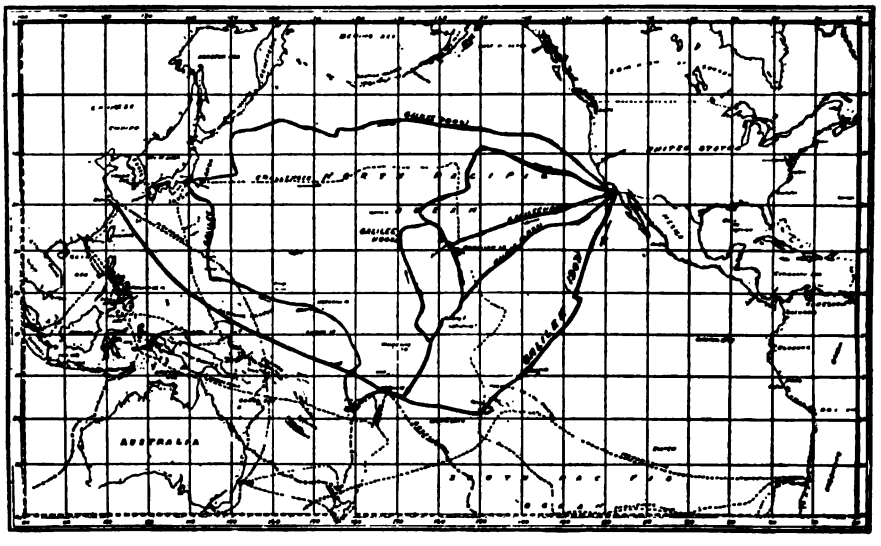


FIG. 3.—MAP OF PACIFIC OCEAN SHOWING ROUTES TRAVERSED BY EXPEDITIONS DESIGNED TO SECURE MAGNETIC DATA

Challenger, 1872–1876 ..... *Gazelle*, 1874–1876 —+—+—
Novara, 1857–1860 × × × × × *Galilee*, Aug. 1, 1905–May 8, 1907 ———

any vessel thus far engaged in oceanic magnetic work. However, the corrections are still large enough so that they require to be taken into account to satisfy the requirements of the problem. These corrections must be determined by special observations, consisting of swinging ship in port and at sea as often as circumstances will permit, which necessarily cause more or less delay in both the field and office work. Unfortunately, experience during the past two years has also repeatedly shown that these corrections do not strictly follow the laws prescribed by the mathematical analysis of the deviations.

Namely, the corrections arise chiefly from the magnetic induction in the soft iron parts of the vessel, and hence are subject to various

accidental conditions, such as length of time pursued by the vessel along any one course, or the amount of buffeting the vessel has been exposed to from the waves, etc. Accordingly, it would be more economical all around, were it possible, to secure an entirely nonmagnetic, specially built vessel. The construction of such a vessel presents no mechanically insurmountable difficulties. It seems a pity that in the very regions where the disturbances due to local magnetic masses are a minimum we should introduce an extraneous source of disturbance by not having an entirely nonmagnetic vessel.

However, conditions did not permit our waiting for such a desired vessel, and the attempt was accordingly made to secure magnetic data as accurately as possible and to solve the problem given to the Committee on Terrestrial Magnetism of the International Association of Academies in 1904, upon the proposal of the late Professor von Bezold, viz., "The determination of the best methods of making accurate magnetic observations at sea."

The following slide (Fig. 3) shows the progress already made in the Pacific Ocean by the magnetic survey yacht *Galilee* up to the end of her second cruise last year. Furthermore, up to date during her present and third cruise she has followed a line from San Diego to Tahiti and the Samoan Islands, and is now on her way to Yap of the Caroline Islands and to Shanghai.[1] From the latter port she will proceed to Midway Island, thence to Sitka, and from there to Honolulu, where it is hoped she will arrive in time to undertake another short cruise before the end of the present year, embracing the region between Easter Island and the Marquesas Islands. As a vessel of the Coast and Geodetic Survey, the *Explorer,* is now *en route* from Baltimore to San Francisco via Cape Horn, and is equipped with the necessary instruments for the determination of the three magnetic elements in the region of the Pacific Ocean bordering upon the west coast of South America, Central America, and Mexico, the end of the present year will witness the completion of a general magnetic survey of the North Pacific Ocean, inclusive of a large portion of the South Pacific Ocean, making it possible to construct more accurate magnetic maps for this region than hitherto available.

Several slides were exhibited of the vessel *Galilee,* showing instruments used, methods of observation employed, and specimen results obtained. The general endeavor is to obtain two entirely independent

[1] The vessel arrived at this port on May 8.

determinations of each magnetic element, declination, dip, and intensity, at different parts of the observing bridge, so as to vary the magnitude and sign of the deviation corrections.

It has been found that declinations and dips can be determined at sea with an absolute accuracy of 5′ to 10′, horizontal intensity to within $\frac{1}{800}$ to $\frac{1}{500}$ part of its value, the precise accuracy depending largely upon the extent of the observations. The principal difficulty in securing results, especially of declination, does not arise from the motions of the ship, but from purely meteorological causes preventing the securing of the necessary solar or stellar observations. Improvement in the present azimuth devices for ocean work is the chief problem remaining.

FIG. 4.—THE "GALILEE" LEAVING SAN DIEGO, CAL., ON HER THIRD CRUISE, DECEMBER 22, 1906, UNDER THE COMMAND OF MR. W. J. PETERS

A comparison of the results of the *Galilee* with those scaled from the most recent magnetic charts shows that the latter give systematically too low declinations between San Francisco and Honolulu by about 1° to 2°, these amounts being exceeded in other parts of the North Pacific Ocean; furthermore, the chart values of the dip are, in general, too small by about 1° to 3°; and the values of the horizontal intensity too high by about $\frac{1}{25}$ part.

In conclusion, some specimen results of extremely interesting fluctuations registered by magnetographs at various magnetic observatories were shown by slides, *e. g.*, effects recorded simultaneously over the entire Earth in connection with the Mt. Pelée eruption of May 8, 1902, as also certain effects recorded in connection with the San Francisco earthquake.

SPEED REGULATION OF HIGH HEAD WATER WHEELS

By H. E. WARREN

Read January 10, 1907.

EVERY one knows that most streams, if traced from the ocean back to their origin, change in character, from a great mass moving at slow velocity in a single channel, to a number of tributaries, each consisting of a fraction of the mass, but with greater and greater average velocity of flow as the mountainous sources are approached.

Since any mass in motion contains energy proportional to the square of its velocity, it is apparent that the power of a stream per mile of length may easily be greatest where the actual amount of water flowing is comparatively small, and indeed it would appear to be generally true that the total power per mile of the combined tributaries would be much greater near the mountainous sources than near the sea.

Partly because the foregoing facts were not appreciated until recent times, partly because the works and habitations of man have been confined to low and approximately level places, partly because no efficient devices had been invented to transform the energy of rapidly flowing water, and principally because there was no means of transmitting energy to a distant place, the utilization of mountainous water powers is of recent growth. For the reasons just stated, it is evident that power development near the sources of streams, or any other place where the fall, by which is meant the change in level, is very rapid, is a very different proposition from that where the fall is gradual and the quantity flowing great.

Considering these two problems, we may point out the characteristics of each as follows: In most places where low heads are available the country is comparatively level and the soil fertile; consequently such regions are populous and supplied with railroads. Generally, manufacturing has gravitated towards the streams for very many reasons. The mills, having been built mostly when trusts and monopolies were unknown, are generally small; therefore the power requirements are

readily met by erecting low dams and directing the flow of water through wheels situated in the factory buildings. Transmission from these wheels is by means of belting and shafting, which form a very large portion of the maximum load. Speed regulation is consequently a simple matter, because such a large part of the load is constant that the largest variations are not great proportionately. Moreover, with an enormous mass in pulleys and belting, the inertia is very great and tends strongly to steady the water wheels. The hydraulic problems are not generally complicated by long water columns or pressures difficult to control.

On the other hand, the utilization of water power where the fall is rapid involves not only the electrical transmission of energy to distant points, but also the construction of a very different type of water wheel, with special control mechanism, long pentstocks to convey the water under high pressure, speed-governing devices of extreme sensitiveness to take care of rapid variations in the electrical load, and water relief apparatus to prevent damage by pressure waves in the long supply pipes.

Considering in detail the special features which accompany the development of water power under high heads, it will appear that some are favorable, while others are the reverse. The fact that the spouting velocity of the water, which varies directly with the square root of the head, is much greater than in low head installations means that the peripheral velocity of the water wheels will be high, and for a similar type of turbine the angular velocity would, therefore, be higher than is usual in low head developments. High velocity of rotation means economy in electrical generators, of which the size and weight for equal output vary nearly inversely with the revolutions per minute. High velocity of rotation also implies great kinetic energy in the rotating parts, which is favorable for speed regulation. In most cases of extremely high head, however, it has been found expedient to make use heretofore of impulse wheels, which run at considerably slower angular speed than reaction turbines of the same capacity; therefore the gain in cost of generators and in kinetic energy of the moving parts is not so great as the increased spouting velocity of the water would indicate.

The great normal pressure of water in high head plants requires careful engineering foresight to prevent trouble. The more obvious effects, such as stress and deformation of the lower part of the pipe

line, with its valves and other connections, can be taken care of without great difficulty; but the control of the water as it rushes to the wheel is an exceedingly serious proposition. In low pressure turbines it is customary to regulate the quantity of water flowing to the wheel by simple gates of the well-known cylinder or wicket type. Entirely aside from the question of efficiency, it is found very difficult to use similar gates where the pressure is very great. Some of the reasons are that such gates are liable to be deformed and made to bind or rub; they then become tremendously out of balance, owing to uneven distribution of the pressure of the water, and they leak so fast when closed as to waste water and keep the wheels in motion continually. The foregoing statement is not an assumption, but is an illustration of what has actually happened in several moderately high head installations in this country where modifications of low head turbines have been used. But these objectionable features are not prohibitive, because governors are made powerful enough to move gates even though they are binding and out of balance, while leakage when the gates are closed may be checked by secondary gates in the pentstocks of the wheels, or the wheels may be brought to rest in spite of the leakage by powerful friction brakes.

High pressure, with its accompanying great velocity of flow, involves extremely difficult work for the designer and builder of reaction turbines. The water passages must be very small in proportion to the output, and yet the contour must be accurate. These small passages are easily clogged; therefore the water supply must be reasonably clear or else filters may be needed. Slight variations in the curvature of the passages are likely to produce very great variations in efficiency. The surfaces must be very smooth and free from abrupt changes of curvature, the material must be tough and homogeneous; otherwise erosion by the rushing water will quickly bring about destruction. The worst problem of all, perhaps, is the construction of a gate or gates which will perform the function of varying the output of the wheel at will, from zero to full load, without interfering with the efficiency of the turbine and which will move with reasonable freedom. The amount of work and thought which has been given towards solving these problems is enormous, for it has been obvious from the beginning that reaction turbines have fundamental advantages over other types of water wheels in lower cost per unit of power.

On account of the very great difficulties in designing and constructing reaction turbines for the utilization of high pressure water power,

there grew up many years ago in America, and to a lesser extent abroad, a strong tendency towards the nearly exclusive use of so-called impulse wheels wherever the head exceeded 100 or 200 feet. Such prime motors, which are also familiar to all under the name of tangen-

FIG. 1.—TYPE OF TURBINE WHEEL USED FOR HIGH HEADS
Entire circumference active when in operation

tial, or Pelton, wheels, are exceedingly simple. In their original form these resembled in principle and action the paddle wheel of an old-fashioned steamboat, made to rotate by the impact against its blades of a stream of water from a fireman's nozzle. Obviously, turning the nozzle towards or away from the vanes would vary the amount of

FIG. 2.—IMPULSE WHEEL DEVELOPING 5,000 HORSE POWER AT 865 FEET HEAD
Active portion consists of lower buckets

water striking them, and consequently the power of the wheel. If the stream were turned so as not to strike the blades, the wheel would come to rest. Evidently the force required to deflect the nozzle would be extremely slight because of the absence of friction or positive tendency to point in any particular direction. The evolution of the impulse wheel has not removed the essential features mentioned above. The vanes have been changed from flat projections to concave double buckets finely polished, and designed to take water which strikes them, and turn it outwards and backwards through an angle of almost 180°, without causing interference or excessive commotion. The nozzle has been supported on trunnions to take the reaction of the jet without interfering with its deflection, and the curvature of the inner surface has been altered by experiment until the stream which issues is so free from eddies as to resemble a glass rod. By these means the efficiency of the impulse wheel when utilizing the entire stream from its nozzle has been made as good as or better than that of the best reaction turbines. Unfortunately, however, the output per unit of weight must still remain at a great disadvantage as compared with a reaction turbine under the same conditions, for in the former the conversion of energy is confined to a very small portion of the rim of the wheel, while in the latter the entire surface is active. The disadvantage of the impulse wheel in output per unit of weight is sometimes lessened by allowing several jets to strike the buckets at different points on the circumference. In many cases the nozzles are fixed so as to direct their streams squarely against the buckets, and other simple means, such as hoods or shields, are provided to deflect a portion or the whole of the water.

The great waste of energy which takes place with an impulse wheel when a portion of the water is being deflected for the purpose of speed regulation has brought about the design of such wheels where the jet of water is not deflected at all, but instead the cross-section of the stream is altered by means of a needle valve in the nozzle. The construction is such that the stream flows through the annular space between the inner surface of the nozzle tip and a peculiar valve spindle, which looks somewhat like a beet with an elongated root, the two parts being held concentric by force of the flowing water. When these parts are properly designed the stream does not remain hollow, as might be expected, but converges to a solid cylinder of water a short distance from the nozzle. By moving the valve spindle back and forth axially, the width of the annular space through which the

water flows may be changed at will, and thus the efficiency of the wheel may be kept high throughout the entire range of output. The only important objection to this type of wheel is that an element of great danger is introduced by such sudden variations in the velocity of the water in the long pipe line which must invariably be used.

In order to get the benefit of safe and good speed regulation, impulse wheels of the very best type are now furnished with com-

FIG. 3.—STREAM ISSUING FROM NEEDLE-NOZZLE AT ENORMOUS VELOCITY TO DRIVE IMPULSE WHEEL

bination deflecting nozzles which have needle valves, the governors being designed to control the deflection, and some other means provided to produce slow movements of the needle valves. Ordinarily with this arrangement the needle valve which regulates the cross-section of the jet is adjusted from time to time by hand as the maximum load varies, so that the governor in order to maintain constant speed is obliged most of the time to direct the stream almost, but not quite, squarely against the moving buckets. If the load increases so that

the portion of the stream which is held in reserve by the governor is inadequate to maintain the speed during sudden peaks in the load curve, the cross-section of the jet is increased by an attendant.

By a device recently invented the need of an attendant to look after this detail may be eliminated. Instead, a small electric or water motor is mounted on the nozzle, so that it may move the needle valve in or out very slowly. Control contacts or valves for the motor are arranged to actuate it in a proper direction whenever the main nozzle is deflected away from a predetermined position by the governor. As a result, the cross-section of the jet will be maintained at a certain margin above that necessary to carry the average load. Such a device is better than

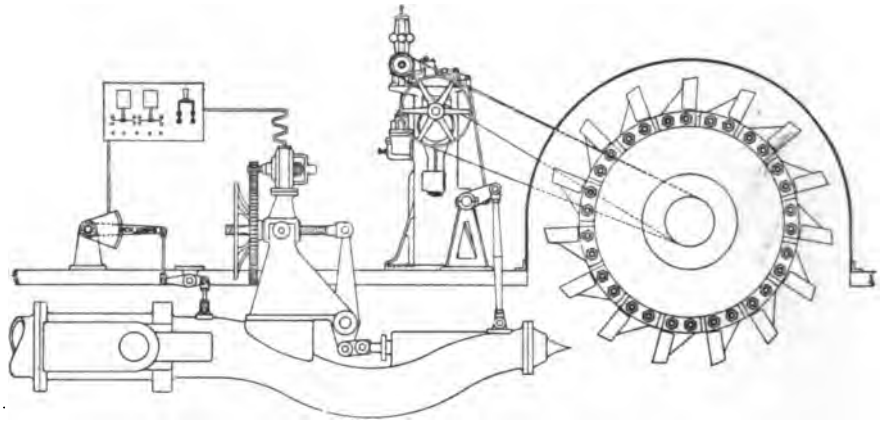


FIG. 4.—AUTOMATIC NEEDLE AND DEFLECTING NOZZLE

manual control because of its unceasing vigilance; it is just as safe because the fastest travel which it can give to the needle valve will not create water hammer; and it is obviously cheaper in operation.

The function of a governor in connection with a water wheel is to maintain the speed nearly constant. In order to do this it must be able to control the water acting upon the wheel; generally it must be able to exert great force. Since the load is liable to change rapidly, the governor must move quickly. Since the governor cannot act at all until the speed has departed from the normal, it is important that it should be exceedingly sensitive to slight speed variations and should begin to move as soon as they occur. Because the speed cannot return to its normal value as quickly as the governor moves, the machine must act and then wait for the speed to return. The governor ought to be

able to act when the water wheel is standing still; otherwise some other means must be used in starting.

The foregoing, which are essential features of a good governor, apply equally to high and low head water powers. A careful analysis will show qualifications which are conflicting and difficult to realize.

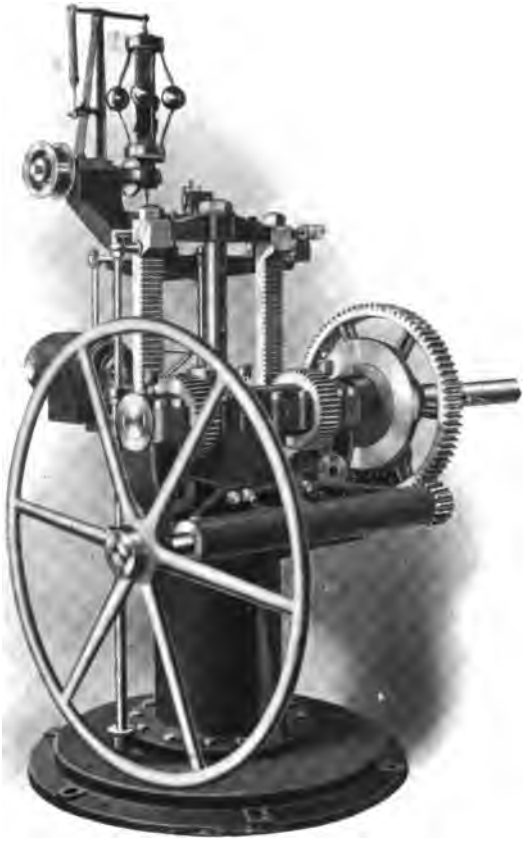


FIG. 5.—HYDRAULIC GOVERNOR, 30,000 FOOT POUNDS BER STROKE CAPACITY, USED WITH LARGE TURBINES

Yet hydraulic governors which are being manufactured today have them all and others in addition. As regards force exerted in action, governors are now in constant service which develop at their normal rating 50,000 pounds push at the piston rod; it is somewhat difficult to imagine a gate which would not budge when urged in such a manner. For speed of action the limit at present on small governors is some-

what less than one-half of one second for a complete stroke, which means that the governor can shut off or turn on the entire supply of water to the wheel within that interval. The largest governors have a maximum speed of from one to three seconds per stroke. Regarding sensitiveness, it is possible to make adjustment while the governor is in action. Variations within one-half of one per cent. cause prompt movements; in fact, it is not easy to measure the smallest variations which will be felt by the machine. The feature of waiting, after it has moved the gates a proper distance, for the speed to return is called anti-racing. This may not be expressed in units, but is quite satisfactory under actual conditions.

The speed regulation of high pressure impulse wheels with deflecting nozzles is the easiest problem in governor engineering. A small regulator developing from 2,500 foot pounds to 7,000 foot pounds is powerful enough for the largest units. This should be of the oil-pressure type. Such machines may be wholly self-contained. The connections between the governor and the nozzle are simple and inexpensive. The degree of speed regulation which can be obtained is about the same as with a steam engine.

The problem of getting the best possible speed regulation from a high pressure turbine or an impulse wheel with needle valve control needs very careful thought if, as is nearly always the case, either of these is located at the end of a long feeder pipe. The great difficulty is that a long column of water possesses so much inertia that its velocity cannot be changed with sufficient rapidity, and moreover the changes in rate of flow which actually occur introduce an element of great danger. A simple illustration will show why this is so. Imagine a turbine operating at the end of a feeder pipe 5,000 feet long. Assume a maximum rate of flow in the pipe of 8 feet per second, which is frequently exceeded. If the head were 400 feet and the pipe 5 feet in diameter this would correspond with an output of 5,600 horse power. In such a case the actual weight of water in the pipe would be slightly over 3,000 tons, which exceeds that of a loaded freight train half a mile long. Now 8 feet per second is five and one-half miles per hour, and it does not require very deep thought to see that it would be a rather difficult operation to start such a train from rest, bringing it to that speed within a second or two; it wouldn't be much easier by the use of the engine alone without brakes to bring such a train back to rest again in the same time interval. Yet this is just

what some engineers expect can be done to an equivalent water column. If the water and pipe were absolutely inelastic, it would be easy to calculate the average pressure in pounds per square inch which would be

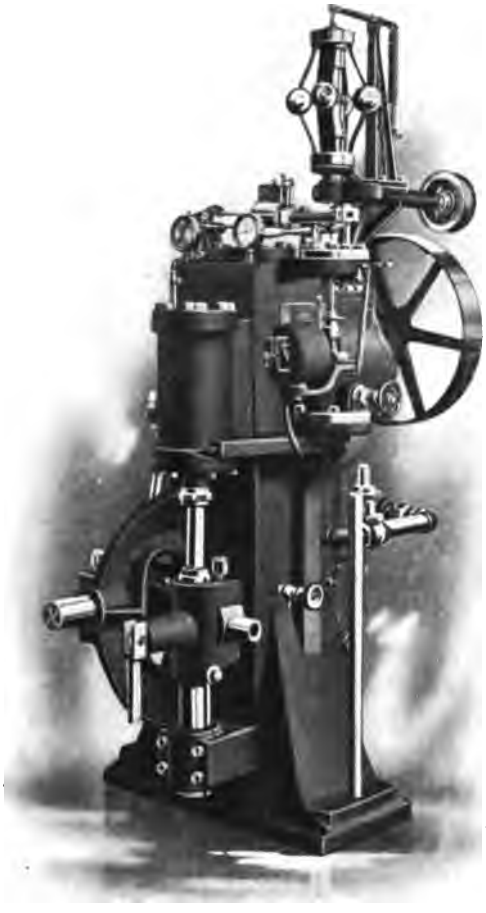


FIG. 6.— HYDRAULIC GOVERNOR, 2,500 FOOT POUNDS PER STROKE CAPACITY, USED WITH IMPULSE WHEELS

required to stop the moving water within, say, two seconds. This would be equal to about one-eighth of the weight of a column of water of 1 square inch section 5,000 feet long, because 8 feet acceleration in two seconds is approximately one-eighth as great as the acceleration due to the weight of a substance acting on its own mass. This amounts

to 271 pounds per square inch, while the static head is only 171 pounds per square inch. As a matter of fact, the pressure induced in stopping the moving water column by the action of a governor upon the gate of the turbine would greatly exceed this amount, because the retarding action would not be distributed uniformly over the two-second period. An exact solution of the problem is impossible because of the irregular movement of the turbine gate in combination with the uncertain elasticity of the water and pipe. While it is impossible to determine the actual initial rise of pressure caused by a sudden closing of the turbine gates, the matter is made even more complex by pressure waves, which, originating near the gate, travel back and forth through the water with the velocity of sound, setting the whole mass into vibration like an organ pipe. Because of these waves there are formed nodes and loops of pressure at various points in the length of the pipe, so that it may happen that the stress will be greatest near the middle.

The foregoing argument shows clearly the need of a relief valve wherever a feeder pipe is so long that dangerous pressures will be generated by the necessarily quick action of a governor. However, this solution is not so easy as it seems, on account of the part played by the pressure waves which run back and forth through the elastic water column. Any ordinary valve, such as is used for steam, would open and close so rapidly as to act like a reed upon an organ pipe, and thus maintain and increase the vibration of the mass. In order to be at all effective, a relief valve must be deadbeat; but it must also open quickly. Its time of closing must be long compared with the vibration pitch of the water column. This latter requirement is rather difficult with the exceedingly long pipe lines, which sometimes bring water several miles. It may be interesting to know that special valves are now built which will open instantly and consume several minutes in closing, the speed of action being, of course, adjustable.

Although it is possible to prevent excessive rise of pressure due to reduction in velocity of long water columns, no means have been devised to produce quick acceleration of the water when, because of a sudden increase in load, the speed of the turbine begins to fall. The governor will open the gates promptly, with the immediate result that the water pressure will drop, and also the already inadequate power of the water wheel; therefore the speed will fall still farther and the governor continue opening the gates until they are wide open. The reason why the pressure falls when the gates open is simply on account

of the inertia of the mass, which cannot keep pace with the demand for water. After a certain time interval, which may be several seconds,

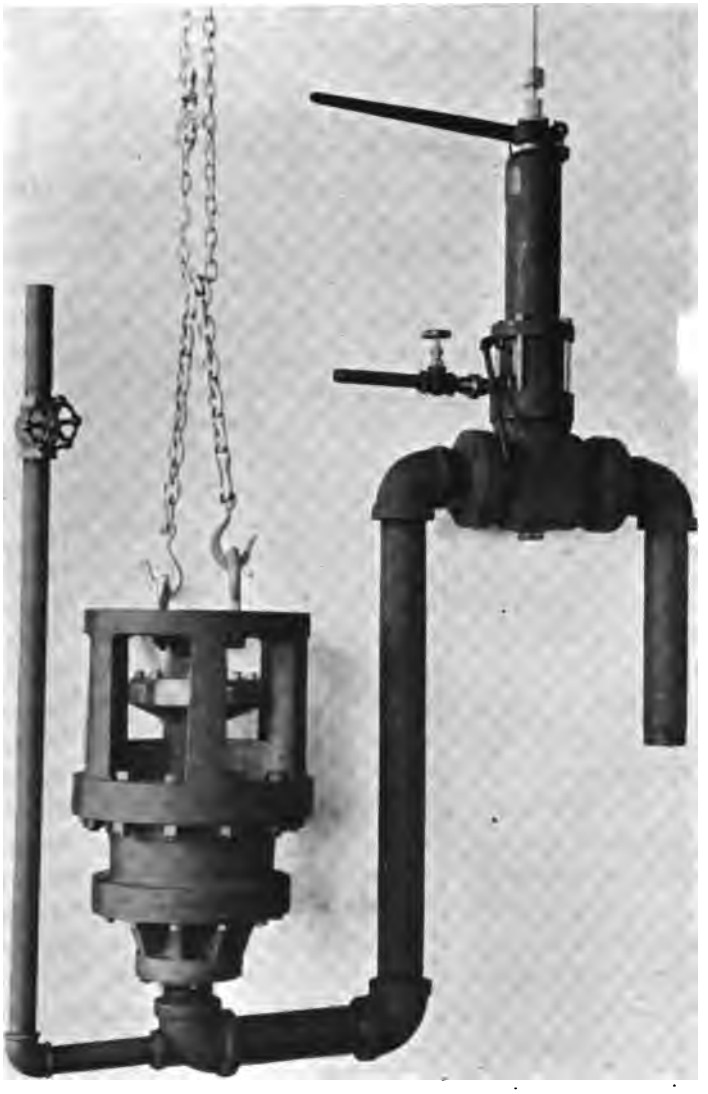


FIG. 7.—HYDRAULIC RELIEF VALVE

the water column will have accelerated sufficiently to supply what is needed by the turbine. By this time, however, the speed may be far

below normal. There will be a rapid acceleration of the water wheel, which will pass normal speed because of the excessive gate opening, and as a result the governor will close the gates quickly, causing the relief valves to operate. If the governor is not made very deadbeat and rather sluggish, this cycle of events will be repeated to the great detriment of the speed regulation. When the governor is made sufficiently deadbeat so as not to encourage pressure oscillation of the water column, it will be found that the speed regulation is poor if the load changes are large and sudden; it is impossible for this to be otherwise, because the water column cannot possibly alter the energy given to the wheel fast enough, whether the gates be in one position or another.

The only complete remedy for the troubles in speed regulation caused by excessive inertia of a water column is some form of by-pass valve directly connected with the water wheel gates, arranged to open as they close, and thus keep the velocity of the column nearly constant. An arrangement of this kind is substantially equivalent, as regards water efficiency, to an impulse wheel with deflecting nozzle. This involves a frequent waste of water equal to that required for the largest load variations, and cannot well be permitted in many installations. Therefore in such power plants as have been described some compromise is usually reached. Speed regulation is partly sacrificed for the sake of water economy. Frequently such stations are connected electrically with others where the hydraulic conditions are favorable to good speed regulation. This arrangement ensures the even speed of the whole system with good efficiency.

The predetermination of speed regulation, which can be obtained under given conditions, is considered of great importance by engineers who are designing power plants. Unfortunately, there is a strong tendency to leave out of consideration the physical laws which are involved, and to expect the governor manufacturer to furnish a certain percentage of speed variation for stated load changes. A governor builder who will guarantee the lowest percentage may get the order, while another who tells the truth is ruled out. These guarantees are sometimes ludicrous, being made without any regard to mathematics or physics. Frequently they are insisted upon when all the necessary data cannot be obtained; at such times the instinct of a weather clerk is the best guide. Conditions are improving, however, and very frequently nowadays sufficient information is supplied so that an accurate prediction can be made. The following is submitted as a comparatively simple analysis of the problem of predetermining speed regulation:

Let S = normal speed in revolutions per minute.

S_1 = speed in revolutions per minute after load change.

K = kinetic energy in foot pounds of revolving parts at speed S.

K_1 = kinetic energy in foot pounds of revolving parts at speed S_1.

$I = \int wr^2$ = moment of inertia or fly wheel effect of revolving parts.

$\left.\begin{matrix} L \\ L_1 \end{matrix}\right\}$ = loads in horse power before and after a change.

p = the horse power output from the water wheel corresponding to L.

p_1 = the horse power output from the water wheel corresponding to L_1.

HP = the full-load horse power output from the water wheel.

$\Delta K = K - K_1$ = the excess energy output from the wheel in foot pounds while the governor is adjusting for a change in load from L to L_1.

$\Delta S = S - S_1$ = temporary change in speed.

δ = percentage temporary change in speed.

g = the acceleration due to gravity = 32.2 feet per second.

T = the time required for the governor to make a stroke.

According to the laws of physics, $K = \dfrac{I 2\pi^2 S^2}{g 60^2}$; (1)

simplifying, $K = .000170\, IS^2$. (2)

As long as the output from the wheel is equal to the load, the speed S and kinetic energy K of the revolving parts will remain constant. The governor is designed to adjust the output of the wheel to correspond with the load, but it cannot do this instantaneously. Consequently, during the time T required to make the adjustment of the control mechanism after a load change there will be a production of energy by the water wheel greater or less than the load. The entire excess or deficiency will be added to or subtracted from the kinetic energy of the revolving parts, and will become manifest by a corresponding change in speed.

Neglecting friction losses, and assuming that the power of the water wheel is proportional to the percentage of the governor stroke and that the movement of the governor after a load change is at a uniform rate, the excess or deficient energy which goes to or comes from the revolving parts after an instantaneous change of load from L to L_1

is measured by the average difference between the power of the wheel and the new load during the time T while the governor is moving, multiplied by T.

Expressed in foot pounds, $\Delta K = \frac{p - p_1}{2} T \times 550.$ (3)

This produces a percentage change in the kinetic energy of the revolving parts of

$$\frac{100\Delta K}{K} = \frac{100(p - p_1)T \times 550}{2 \times .000170 IS^2}; \quad (4)$$

$$= 162{,}000{,}000 \frac{T}{IS^2}(p - p_1). \quad (5)$$

Now the relation between speed of revolution and kinetic energy of the revolving parts is evidently

$$\frac{K_1}{K} = \frac{S_1^2}{S^2}. \quad (6)$$

By algebra,

$$\frac{K_1 - K}{K} = \frac{S_1^2 - S^2}{S^2}; \quad (7)$$

$$= \frac{(S_1 + S)(S_1 - S)}{S^2}. \quad (8)$$

Putting $S_1 - S = \Delta S$

and $K_1 - K = \Delta K.$

For small differences between S and S_1, this becomes approximately

$$\frac{\Delta K}{K} = \frac{2S\Delta S}{S^2}. \quad (9)$$

$$\therefore \frac{\Delta K}{K} = \frac{2\Delta S}{S}. \quad (10)$$

Substituting (10) in (5),

$$\frac{200\Delta S}{S} = 162{,}000{,}000 \frac{T}{IS^2}(p - p_1). \quad (11)$$

$$\therefore \delta = \frac{100\Delta S}{S} = 81{,}000{,}000 \frac{T}{IS^2}(p - p_1). \quad (12)$$

If $p = HP$, $p_1 = 0$, and $T = 1$,

then the percentage speed variation for 100 per cent. load change, if the governor makes a complete stroke in one second, is

$$\frac{100\Delta S}{S} = \frac{81{,}000{,}000 HP}{IS^2}. \quad (13)$$

From the form of equation (12) it is apparent that the percentage speed variation is directly proportional to the slowness of the governor; *e.g.*, if T is four seconds, the variation in speed is four times as great as when T is one second. Under certain conditions the effect of the governor in promptly adjusting the output of the water wheel after a load change is interfered with by the inertia of the water column in the pentstock, and in such cases the predetermination of speed variation is sometimes very difficult. For simple deflecting nozzles with tangential wheels and with most turbine installations the formula (12) is of great service.

Of the quantities in the equation (12), there is one, viz., T, which cannot be exactly determined. Any governor manufacturer will state the time required for a complete stroke of one of his governors, but it should not be assumed that fractions of the stroke will be covered in correspondingly lesser intervals. Experience shows that short governor movements take place at a much slower rate of travel than long ones. It is necessary that this should be so in order to prevent overtravel in adjusting the output of the water wheel. As a matter of fact, one may assume, without introducing a serious error into the calculations, that the time T required for any governor to alter the power of a water wheel after a great or small sudden load change will be approximately constant and equal to the time required for a full stroke.

As an application of the foregoing formula consider the following simple problem:

Given an 8,000 horse power tangential wheel with deflecting nozzle, running at 400 revolutions per minute, driving a revolving field alternator. The fly wheel effect or $\int wr^2$ of the revolving parts is estimated equal to 500,000 pounds at 1 foot radius. The speed of action of the governor will be one second for a full stroke. Required the percentage speed variation for (*a*) 100 per cent., (*b*) 50 per cent., and (*c*) 10 per cent. load changes.

Referring to equation (12),

$$T = 1, \quad I = 500{,}000, \quad S = 400.$$

(*a*) For 100% load change $(p - p_1) = 8{,}000$.

(*b*) For 50% load change $(p - p_1) = 4{,}000$.

(*c*) For 10% load change $(p - p_1) = 800$.

Substituting in equation (12),

$$(a) \quad \delta = 81{,}000{,}000 \frac{1 \times 8{,}000}{500{,}000 \times 400^2} = 8.10\%.$$

$$(b) \quad \delta = 81{,}000{,}000 \frac{1 \times 4{,}000}{500{,}000 \times 400^2} = 4.05\%.$$

$$(c) \quad \delta = 81{,}000{,}000 \frac{1 \times 800}{500{,}000 \times 400^2} = .81\%.$$

After a power plant is in operation, it is often necessary to determine, among other facts, whether the speed regulation is as good as was guaranteed by the governor manufacturer, or at any rate as good as it should be. The instruments for making such tests are as numerous as they are unreliable. Ordinary tachometers cannot be depended upon at all unless they have been carefully calibrated, and even then most of them have defects which make accurate determinations impossible.

There is another class of instruments, known as frequency indicators, upon which reliance is sometimes placed. These have nicely graduated scales, with proportional divisions purporting to show changes in frequency, cycle by cycle. If they told the truth they would be exceedingly useful, for by merely connecting one of them in circuit with an alternator it would be possible to tell immediately the speed variations occurring either in connection with the regular operation of a plant or during prearranged variations in load. These frequency indicators are generally correct for the number of cycles where they are intended to be used, but cannot usually be depended upon over any range of scale.

A method of obtaining simultaneous measurements of load, voltage, and speed has been devised by the author which is absolutely free from instrumental defects, and which, while requiring only one or two skilled men for its use, will give results of great value in any power plant where there are two or more independent alternating current units.

It is evident that the number of cycles per second of current generated by any alternator could be used to measure the speed if these cycles could be accurately counted. The oscillograph provides means for doing this in a very interesting way. This instrument, which is well known to electrical engineers, is a sensitive reflecting galvanometer, which has such an exceedingly short period of vibration and is so deadbeat in action that the actual current wave, varying, even though it may, as rapidly as several hundred times a second from a

positive to a negative value, can be accurately followed and recorded on a sensitive photographic film. If the film could be moved at an absolutely uniform rate, so that the trace of the current value would be drawn as an approximate sine curve, it would be necessary merely to measure the spacing of this curve in order to determine the frequency of the generator and, consequently, its speed. It is not easy, however, to provide absolutely uniform motion for the film, and there are some other difficulties in the way. Since, however, several oscillograph curves may be superimposed on the same film, it is not necessary that the sensitive photographic surface should move at a uniform rate, because one sine curve may be measured in the terms of another sine curve. If one of these is known to pass through a constant number of cycles per second, it may be adopted as the standard unit of time, and its waves, as shown on the film, be used to measure the number of cycles per second of the other curve and, consequently, the speed variations of the machine under test.

The measurement of the comparative frequency of the two curves becomes a very simple matter if they are allowed to overlap on the film, because in such a case interference effects are produced in a very beautiful manner. These interferences are due to the fact that at times the traces of both curves overlap on the film so as to produce a single line; while at other times, one curve having gained part of a cycle over the other, the two lines will be side by side and more or less confused. When the speed of motion of the film is right, the negative shows alternate shaded bands, the distance apart of which, when counted in cycles, is an accurate measure of the relative speeds of two generators being compared; and if one of these generators is running at constant speed, it gives an absolutely clear record of the very smallest variations in speed of the other machine. It will be observed that there are no possible instrumental errors by this method. Inertia, sluggishness, friction, faulty calibration, and other objectionable features of mechanical devices are wholly eliminated, and results are obtained which must be considered absolutely final if just one condition is fulfilled. Everything depends upon one generator running at constant speed. In practice it is not difficult to fulfill this condition with ample precision. To do so the generator, which is to serve as a standard measure of time, must be given a perfectly steady load, or, better still, no load at all, excepting the trivial current required by the oscillograph. The gate of the water wheel which drives it should

be disconnected from its governor and fixed in position. The water pressure upon the wheel should be maintained very nearly constant. The generator should be allowed to run fifteen or twenty minutes before measurements are made. Its speed should be observed very carefully by a sensitive recorder of some kind in order to be sure that it is steady. A frequency indicator will answer very well for the purpose, even though its graduations may be far from correct, because it is to be borne in mind that steady speed is the only desideratum. The great inertia of the revolving parts of the water wheel and generator in the absence of any external load will be found to maintain the speed with remarkable uniformity. There should be no trouble at all in keeping this standard machine steady within 0.1 per cent. without any difficult manipulation of the water wheel gate. The frequency of this standard machine should be adjusted 5 per cent. or 6 per cent. below or above that of the normal frequency of the machine of which the speed is to be measured.

Assuming that the standard generator is running 5 per cent. in speed below the normal frequency of the machine under test, which is the case with the curves shown (Fig. 8), it is clear that the fast machine should gain five cycles over the standard in 100 cycles; or, in other words, the interference points should be twenty cycles apart. If, however, the machine under test should drop in speed 5 per cent., it would then have the same frequency as the standard machine, and the interference points would be an infinite distance apart. If the loaded machine should gain 5 per cent. above its normal speed, it would then be 10 per cent. faster than the standard one, thus gaining ten cycles in each 100, so that the interference bands would be spaced at ten cycle intervals. The extreme precision of the method is shown in the large variation in the spacing of these interference bands, corresponding to comparatively small variations in relative speed. Another great advantage of the method over any other, however, lies in the fact that not only is the speed of a machine under operating conditions determined with extreme precision, but also that the voltage of such a machine is recorded simultaneously, for the amplitude of the oscillograph curve depends precisely upon the voltage of the machine being tested. By measuring the width of the curve, the voltage value corresponding to each speed value is obtained.

Furthermore, it is possible to obtain simultaneous measurements of the current output from the loaded machine, which means practically

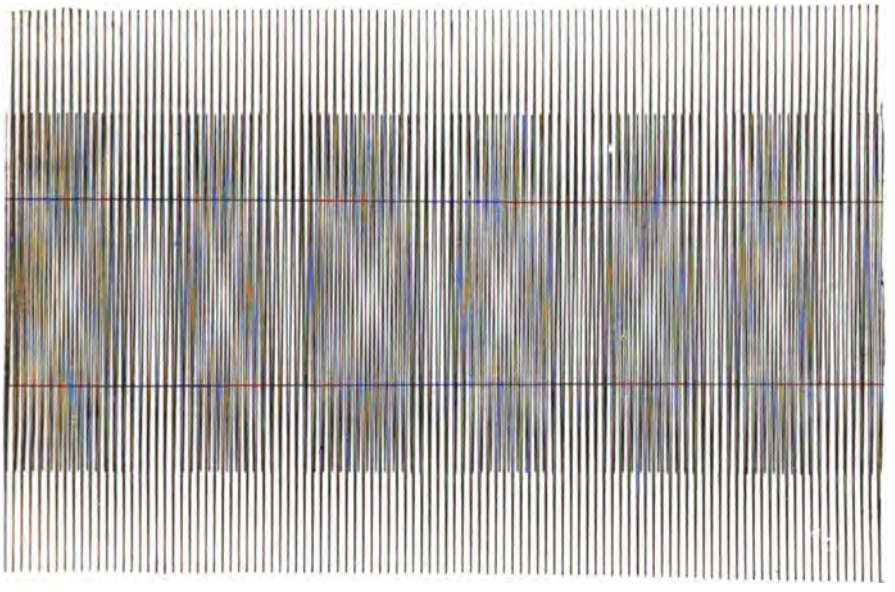


FIG. 8.—OSCILLOGRAPH RECORD FOR SIX SECONDS
Middle horizontal lines indicate amplitude of current curve

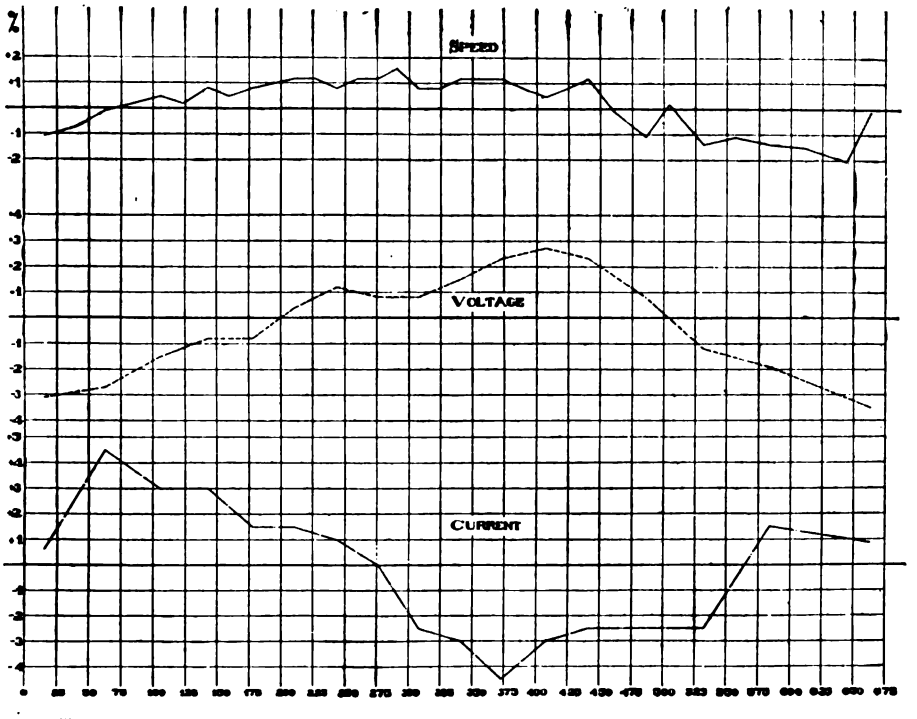


FIG. 9.—PLOT SHOWING RELATION OF SPEED, VOLTAGE, AND CURRENT FROM OSCILLOGRAPH RECORD ABOVE

the variations in load, and this is the most important feature of all. To do this a third oscillograph mirror is impressed into service, being connected with a current transformer in circuit with the generator under test, so that the amplitude of the curve traced by the light reflected from this mirror shall indicate at every point on the sensitive film what the actual output of the generator was, corresponding to the speed and voltage shown by the other two curves. Such a record sheet as has been described, one-fourth of which is shown in the chart (Fig. 8), reproduced with the omission of the current curve of which the amplitude is indicated, contains a marvelous amount of information to the one who can read its secrets. The speed, voltage, and current curves which are shown were obtained by a careful analysis of the entire original record, which is 4 inches wide and about 12 inches long. The lines are spaced so closely on this record as to require the use of a weak microscope in order to make them clear, but there is no possible question about the accuracy of all the results which are given. This method makes it possible to conduct a speed test of any alternating current unit, either steam or water driven, under actual load conditions, and is therefore of much greater value than any test, however accurate, under special conditions, which are never exactly the same as when in service.

MAXIMUM LIVE-LOAD BENDING MOMENTS AND SHEARS FOR BRIDGES CARRYING ELECTRIC CARS[1]

By FRANK P. McKIBBEN

In designing bridges to carry electric railways one should bear in mind that besides the ordinary passenger cars there are other types which frequently should be considered, namely, construction, service, and freight cars. The development of freight traffic upon electric roads makes the consideration of the freight car an important element in choosing loads to be used in designing. However, as the weight and wheel spacing of service and construction cars will vary widely from case to case, only passenger cars will here be considered.

In the last eight or ten years the increase in weight of single-truck cars has been so small and that of double-truck cars so large that, in designing, the latter type only need be used. Except in some special cases of unusually heavy urban or interurban railways, it seems reasonable to assume for a passenger car a double-truck car weighing, together with its maximum load, 100,000 pounds. This should be sufficient to provide for a considerable future increase in weight of cars; but, judging from past experiences with such increases of locomotives on steam railroads, it is difficult to predict with any certainty regarding future loadings for electric cars. In the special cases to which reference is made above, where unusually heavy cars are now in use a loading of 120,000 pounds should be used. It should be remembered that the weight of a car is sometimes unequally distributed over its wheels.

The average unloaded weight of the heaviest double-truck passenger cars now being operated upon fifty-seven electric railways of Massachusetts is 40,000 pounds. The smallest weight used in finding this average is 20,000 pounds and the largest 72,800 pounds. These figures give the weight of the car alone. Assuming 150 passengers at 120 pounds each, the loaded weight of the average car becomes 58,000 pounds and the maximum 90,800 pounds. The average wheel base of a truck for these cars is 5 feet, and the average distance centre to

[1] Reprinted, with slight alterations, from Engineering News, April 4, 1907, 57, No. 14, 372–373.

centre of trucks is 20 feet. This makes the spacing between rear wheel of front truck and front wheel of rear truck 15 feet. The wheel spacing between cars, when two or more cars are run coupled, will not be far from the same amount, so that the concentration of a single car is to be regarded as a maximum for all spans less than 45 feet long.

The criterion for finding the position of a system of concentrated wheel loads to produce the greatest possible bending moment upon a given span is found as follows:

Let the span and loads be as shown in the figure on page 214.

R is the resultant of all the loads on the span, x its distance from the right support, and a its distance from the load P_8. Neglecting the dead load and considering only the concentrated loads, it is evident that the maximum moment will occur at a wheel which is near the centre of the span. The expression for the moment at P_8, this load being one near the centre of the span and nearest the resultant of the loads on the span, is,

$$M = \frac{Rx}{L}(L - x - a) - \Sigma Pd, \tag{1}$$

where ΣPd is the summation of the moments about P_8 of the loads to the left of P_8.

To find the position of the resultant R such that the moment at P_8 is the greatest that can occur at P_8, with the assumed loads on the span, we must differentiate equation (1), place the first differential equal to zero, and solve for x, thus:

$$\frac{dM}{dx} = \frac{R}{L}(L - 2x - a) = 0. \tag{2}$$

Solving equation (2) for x, we have,

$$x = \frac{L}{2} - \frac{a}{2}.$$

This value of x shows that if the loads assumed are on the span the maximum moment possible at load P_8 will occur when the *centre of the span is midway between the load P_8 and the resultant R.*

In applying this principle, it will generally happen that not all the wheels of a series can be placed on the span at one time, at least not in such position as to satisfy the condition as to the resultant R. It then becomes necessary to try several positions of the series of loads. The method of procedure is, then: Assume some of the loads on the

TABLE OF LIVE-LOAD END SHEARS AND MOMENTS IN BRIDGES CARRYING ELECTRIC CARS

100,000 lb. Car — 12,500 lbs, 12,500 lbs, 12,500 lbs, 12,500 lbs — 5′, 15′, 5′ — (1) (2) (3) (4) — Wheel Loads

Maximum End Shears						Maximum Moments					
Span in Feet	Wheels on Span for Max.	Max. End Shear (lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. End Shear (lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. Moment (ft. lbs. per Rail)	Span in Feet	Wheels on Span for Max.	Max. Moment (ft. lbs. per Rail)
5		12500	51		37700	5		15600	51		401300
6		14600	52		38000	6		18800	52		419500
7		16100	53		38200	7	1-Wheel	21900	53		425800
8		17200	54		38400	8		25000	54		438000
9		18100	55		38600	9		29300	55		450300
10		18750	56		38800	10		35200	56		462600
11		19300	57		39000	11		41100	57		474900
12		19800	58		39200	12		47000	58		487100
13		20200	59		39400	13		53000	59		499400
14		20500	60		39600	14		59000	60		511700
15	2-Wheels	20800	61		39800	15		65100	61		524000
16		21100	62		39900	16		71200	62		536300
17		21300	63		40100	17		77300	63		548700
18		21500	64		40200	18		83400	64		561000
19		21700	65		40400	19		89600	65		573300
20		21900	66		40500	20	2-Wheels	95700	66		585700
21		22600	67		40700	21		101900	67		598000
22		23300	68		40800	22		108000	68		610300
23		23900	69		40900	23		114200	69	4-Wheels	622700
24		24500	70		41100	24		120400	70		635000
25		25000	71		41200	25		126600	71		647400
26		26000	72	4-Wheels	41300	26		132800	72		659800
27		26900	73		41400	27		138900	73		672100
28		27700	74		41600	28		145100	74		684500
29		28400	75		41700	29		151300	75		696900
30		29200	76		41800	30	3-Wheels	159700	76		709300
31		29800	77		41900	31		169000	77		721600
32		30500	78		42000	32		178300	78		734000
33		31100	79		42100	33		187500	79		746400
34		31600	80		42200	34		196800	80		758800
35		32100	81		42300	35		207600	81		771200
36		32600	82		42400	36		219500	82		783600
37		33100	83		42500	37		231500	83		796000
38		33600	84		42600	38		243500	84		808400
39	4-Wheels	34000	85		42600	39		255500	85		820800
40		34400	86		42700	40		267600	86		833200
41		34800	87		42800	41	4-Wheels	279600			
42		35100	88		42900	42		291700			
43		35500	89		43000	43		303900			
44		35800	90		43100	44		316000			
45		36100	91		43100	45		328100			
46		36400	92		43200	46		340300			
47		36700	93		43300	47		352500			
48		37000	94		43400	48		364600			
49		37200	95		43400	49		376900			
50		37500	96		43500	50		389100			

span so as to bring the heavy loads as near the centre of the span as possible and so as to have as many loads on as possible. Find the position of the resultant of these loads, and place the centre of the span midway between the resultant and the nearest load. If all the loads

assumed on are now really on the span, compute the moment at the nearest load just mentioned. If when the above assumed loads are placed in the position just cited some of the loads assumed on the span are really off the span, it is then necessary to try again, using a new resultant. Unless one can tell by inspection, it would be necessary to compute in this manner the maximum moment at several of the loads until the greatest possible moment is found. This latter is called the absolute maximum moment. It is evident that when the resultant coincides with one of the loads the greatest possible moment that can occur at this wheel is when it and the resultant lie at the centre of the span.

Passing now to the study of the absolute maximum moments under a double-truck electric car with four equal axle loads with a wheel spacing of 5—15—5 feet, as shown at the head of the subjoined table, we see that there are four cases, namely, where the maximum moment is caused respectively by one, two, three, or four loads on the span. Obviously for certain short spans only one load on the span will cause the maximum; for somewhat longer spans two loads, etc. The limiting lengths separating these groups can be computed.

Case 1. One Load Only on the Span.—The maximum moment will occur at the centre when the load is at the centre. It is equal to

$$M_1 = \frac{PL_1}{4}, \tag{3}$$

where P is one wheel load and L_1 is the length of span.

Case 2. Two Loads on the Span.—Place the wheels so that the centre of the span comes midway between the resultant of the two loads and one of the loads, and the maximum moment will occur at the load which is 1¼ feet from the centre, and is equal to

$$M_2 = \frac{2P\left(\frac{L_2}{2} - \frac{5}{4}\right)^2}{L_2}. \tag{4}$$

Case 3. Three Loads on the Span.—The resultant of three loads will lie 3⅓ feet from load No. 2. Hence the maximum moment will occur at wheel No. 2 when the centre of the span lies 1⅔ feet from the load and is equal to

$$M_3 = \frac{3P\left(\frac{L_3}{2} - \frac{5}{3}\right)^2}{L_3} - 5P. \tag{5}$$

Case 4. Four Loads on the Span.—The maximum moment will occur at load 2 when this load is 3¾ feet from the centre, and is equal to

$$M_4 = \frac{4P\left(\frac{L_4}{2} - \frac{15}{4}\right)^2}{L_4} - 5P. \qquad (6)$$

By equating equations (3) and (4) and calling $L_2 = L_1 = L$, we can find the length of span below which only one load will produce the maximum moment and above which two loads 5 feet apart will give greater moments than the single load, thus:

$$\frac{PL}{4} = \frac{2P\left(\frac{L}{2} - \frac{5}{4}\right)^2}{L},$$

from which $L = 8.5$ feet.

Similarly, by equating equations (4) and (5) we find the length of span below which two wheels give greater moments than three wheels,

$$\frac{2P\left(\frac{L'}{2} - \frac{5}{4}\right)^2}{L'} = \frac{3P\left(\frac{L'}{2} - \frac{5}{3}\right)^2}{L'} - 5P,$$

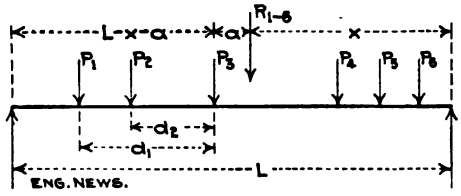
from which $L' = 29.3$ feet.

In a similar manner, by equating equations (5) and (6), we find that L'' equals 34.4 feet; that is, for spans less than 34.4 feet three wheels give greater moment than four wheels, while for spans over 34.4 feet four wheels give the greater moment.

It is customary to add to the above absolute maximum live-load moment the dead-load moment at the centre of the span. Except in cases where the absolute maximum moment occurs at the centre of the span, this is slightly incorrect, but is on the safe side.

The determination of the maximum end shears is very simple. It is evident that for spans of 5 feet and under the maximum end shear will occur with one wheel on the span; for spans between 5 and 20 feet with two wheels; between 20 and 25 feet three wheels; and above 25 feet four wheels on the span. In each case the leading wheel is placed just at the support.

The accompanying table of moments and shears has been worked out for a 100,000-pound car with a wheel spacing of 5—15—5 feet, and has been carried to those lengths of spans where a uniformly



distributed load of 1,800 pounds per foot of track causes maximum moments and end shears equal to those caused by one car.

It is interesting to notice that if the dead load be taken into account the common derivation for the maximum moment at load P_8 is incomplete. The expression for the moment may be written as follows, with reference to the accompanying figure:

$$M = \frac{Rx}{L}(L - x - a) - \Sigma Pd + w(L - x - a)\frac{(x + a)}{2},$$

where w is the uniform load per unit of length. The value of x, which will make M a maximum, is obtained by differentiating this equation with respect to x, and placing the result equal to zero. This process gives

$$x = \frac{L}{2} - a\left(\frac{wL + R}{wL + 2R}\right).$$

Since in this value of x the part within the parentheses is greater than one-half, the value of x is less than for the case where only the live load was considered; which means that for the exact absolute maximum moment the load P_8 should be slightly nearer the centre than previously found.

To compare the usual with this exact method let us take a 60-foot span with a 100,000-pound car and a total dead weight of 800 pounds per foot. The absolute maximum moment for the live load alone is

$$= \frac{50000(30 - 15/4)^2}{60} - 62{,}500 = 511{,}719 \text{ foot pounds per rail.}$$

The dead-load moment at the centre is 180,000 foot pounds per rail. The customary approximate method of adding the absolute maximum live to the maximum dead moment would, therefore, give in this case a total amount of 691,719 foot pounds; whereas the correct method would give a combined maximum moment of 689,451 foot pounds. All of which goes to show that the customary approximate method is sufficiently accurate.

The analysis and computations in this article deal only with bridges in which the load comes directly on the main girders.

TRIP OF THE AMERICAN INSTITUTE OF MINING ENGINEERS TO MEXICO[1]

By ROBERT H. RICHARDS

THE American Institute of Mining Engineers held their fall meeting in Mexico, in November, 1901. The members were carried on two trains, which most of the engineers joined in Chicago, and visited various points in Mexico, holding their official meetings for the reading of papers in the different towns as they went, visiting the mines, concentration works, amalgamation works, and smelters.

The Institute was received in the most cordial manner by the Mexicans, who treated them really as the nation's guests. Nothing that could be done for the comfort of the engineers was omitted. On the arrival of the trains in a town the bands played, the members were decorated with flowers as they came from the train, and were officially welcomed by the officials of the town; means were provided to send them to the mines or works in the neighborhood, and in many cases balls and banquets were given in honor of the guests. Such profusion of kindness and generosity was difficult to reciprocate, but the mining engineers did so to the utmost of their ability.

Among the many pleasant things that were done, loving cups were given to Carlos F. Landero and Rafael de Arozarena, both of whom were leaders in the entertainments.

The Mexican bull fight is the greatest treat, in the eyes of the Mexicans, that can be offered to guests. Accordingly, one was provided at Chihuahua, the first place visited. The engineers and their wives all went to see the bull fight, in order to show their appreciation of the delicate attention shown by the Mexicans. It was, however, quietly whispered over the wires that the bull fight was not the American idea of entertainment, and, as a result, no further invitations were given.

[1] A talk before the Mining Society of the Massachusetts Institute of Technology on Tuesday, 9 April, 1907.

A visit was made from Chihuahua to the Descubridora mine, from which a great deal of rich silver ore has been shipped to the smelters. The ancient pateo process for amalgamation of silver ores was inspected at several places, Zacatecas and, best of all, Pachuca.

The pateo process of Mexico and South America is one of great interest, both from its early appearance as a means of extracting silver and on account of its comparatively high efficiency. The process consists in breaking by hand to about 1 inch in size, by an edge roller to the size of Indian corn, and by an arastra, or drag stone, down to pass through about a 60-mesh sieve. The amalgamation takes place in an open yard called pateo, with very smooth pavement of stones, made so as to be impervious to mercury and water.

The finely pulverized ore, in the condition of mud, is run out on to this pavement and penned into areas holding about 500 tons each. It is then allowed to dry sufficiently for the subsequent operation. The pulp is stirred by turning mules and horses in to walk about in it, the layer of mud being about a foot thick. These animals stir the mud for twelve hours in the day. At periodic intervals mercury is sprinkled in, and the consistency of the mud is held so as to prevent the mercury from settling quickly through it to the bottom. The stirring by the animals brings the mercury in contact with the ore particles and the ore in contact with the air. After several weeks of stirring, adding mercury, testing to ascertain the condition of the extraction, and the adding of chemicals, the whole mass of pulp is liquefied by water and run out into a separator, where the amalgam is caught and the tailings run to waste. The amalgam is then distilled, the mercury recovered, and the residue is melted into bars and shipped to the mine.

At Guanajuato is the ancient silver vein, from which it is said two thousand million dollars of silver have been taken in two hundred years; at Guadalahara, the home of the Mexican drawn work, the wives of the engineers had a special treat; in Mexico City the engineers were cordially welcomed by President Porfirio Diaz in his castle at Chapultepec, from which a glorious view could be had of the beautiful snow mountains Popocatepetl and Iztaccihuatl. The wonderful old aqueduct standing on arches is well represented by fragments; the monster drainage canal which has saved the city from destruction by turning away the water from the old lake bottom in which the city is situated proved especially interesting.

The cathedral in Mexico City, which is the finest in Mexico and

one of the fine cathedrals of the world, was visited by the party. An extremely interesting visit was made to the wonderfully rich cathedral at Guadalupe. The priesthood of this cathedral owned a silver mine, and much of the silver was used in enriching the various altars, altar rails, and other parts of the building. At Cuernavaca the engineers saw the beautiful home of Cortez, and later of Maximilian, where these potentates delighted to live during their vacations from the active work of governing the nation.

At Aguascalientes the engineers took a bath in one of the hot springs, and at this point, as well as at San Luis Potosi and Monterey, they visited the great silver lead smelting establishments. At the latter place they also found the extensive new iron works for smelting iron and making Bessemer steel. At Tampico they took a dip in the Gulf of Mexico, with flocks of funny pelicans flying about, but they were warned to keep in shallow water for fear of sharks.

Coming north they visited the gold mine of Baratoran, and then came up by way of Eagle Pass into the States. They passed through the great Houston oil region of Texas just at the time it was reaching its climax.

When the engineers sought for a means of expressing their gratitude to the Mexicans which would be most highly appreciated, they found it to be in the placing of a profusion of beautiful flowers, in which Mexico abounds, upon the grave of Juarez, the patriot president.

The paper was illustrated by lantern slides showing the points mentioned above and many others.

THE HEALTH OF EMPLOYEES IN THE NEW YORK SUBWAY

By GEORGE A. SOPER

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INTRODUCTION

This paper is practically identical with a report made in May, 1907, to the Board of Rapid Transit Commissioners for the city of New York, and describes an investigation into the possible effects of the metallic dust of the subway on the health of the employees.

This work was the outcome of an investigation made in 1905 concerning the condition of the subway air, which was described in a paper read by the author before the Society of Arts, November 22, 1906.[1]

Acknowledgment of Assistance

Thanks are due to many persons for help. The Interborough Rapid Transit Company, through Mr. Frank Hedley, General Manager, granted requests for information concerning the men and furnished the 100 employees who were examined.

The physical examinations and analyses were made with much skill

[1] The Technology Quarterly, 20, No. 1, March, 1907.

by Dr. James Alexander Miller, Instructor in Physical Diagnosis at the College of Physicians and Surgeons, assisted by Doctors H. C. Hanscom, J. M. O'Connor, and I. O. Woodruff. In the autopsies and subsequent histological examinations thanks are due to Dr. J. H. Larkin, Adjunct Professor of Pathological Anatomy, and to coroner's physicians, Doctors T. D. Lehane and P. F. O'Hanlon. To Dr. Frank B. Mallory, Associate Professor of Pathology, Harvard Medical School, who collected records to show the pleurisy found in 1,008 autopsies performed at the Boston City Hospital, the author is also indebted. Finally, a number of eminent pathologists and medical practitioners aided the work by valuable suggestions and opinions.

PLAN OF THE INVESTIGATION

It was intended that the investigation should be so made as to detect any physiological effects which might be caused by the dust of the subway, whatever they might be. Special care, however, was taken to look for early signs of more serious disease of the lungs, which exists to an excessive extent among persons engaged in dusty occupations.

Physical examinations were made of a sufficient number of subway employees to determine the condition of the average man. Supplementary to these, bacteriological and chemical analyses were made of their sputum, urine, and sweat.

To determine to what extent dry pleurisy existed among persons not engaged in subway work, examinations were made of 200 men, representing twenty different occupations.

To help arrive at an understanding of the possible effects of the subway dust, data were collated concerning its chemical composition, physical properties, and the weight of dust in a given volume of subway air. The bacteria associated with this dust were also considered.

The condition of the air and the work of the men were compared with the conditions which exist in such vocations as stonecutter, knife grinder, metal polisher, and other dusty occupations in which a high mortality occurs.

It being desirable to obtain an accurate understanding of the anatomical condition of the men, and as this could be had only by dissecting their bodies after death, arrangements were made to have as many autopsies as practicable performed upon the remains of

employees killed by accident in the subway during the period covered by the investigation.

Light was thrown upon the frequency with which pleurisy was found at autopsy by reviewing the records of a large number of reports of *post-mortem* examinations made elsewhere.

THE CONDITION OF THE AIR

Investigations which were made for the board from July, 1905, to January, 1906, showed that the chemical condition of the air of the subway, in spite of unpleasant odors and heat, was remarkably good.

Carbon dioxide, the measure of vitiation used as determined by 2,084 analyses covering practically all times and places, was found to be but little higher in the subway than in the streets. The average for the subway was 4.81, and for the streets 3.67. These figures represent parts of carbon dioxide in 10,000 volumes of air.

There was ample oxygen. The average of eighty analyses gave 20.60 per cent. of oxygen for the subway as against 20.71 per cent. for the streets.

The analyses, checked by observations of air currents, indicated that the atmosphere of the subway was completely renewed at least every half hour before any material improvements were made in the methods of ventilation.

There were two principal reports made to the board as a result of the air investigations.[1] A paper dealing with the facts more especially of medical interest was read before the New York Academy of Medicine on March 15, 1906.[2] A second paper dealing with the analytical and meteorological methods was read before the Society of Arts at Boston on November 22, 1906, and published in the TECHNOLOGY QUARTERLY,[3] Boston.

Summarizing the opinions which the author formed at the conclusion of that investigation, the principal possibilities for harm in the air, aside from rapid changes of temperature and strong draughts, lay in the presence of the black metallic dust. The principal characteristics of this dust will now be described.

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[1] New York City Record, February 27, 1906.

[2] New York Medical Record, April 21, 1906.

[3] Vol. 20, No. 1, pp. 58–118.

Physical and Chemical Composition of the Dust

When examined microscopically the dust was found to be composed of particles of many substances, including innumerable fine, flat plates of iron. These iron particles could be seen by a sharp eye glistening upon the hats and garments of persons after a short ride in the subway. The clothing of the employees gathered this dust, and their hands, bodies, and linen became discolored with it.

Large particles of iron could readily be seen at the stations glistening upon the roadbed. A common horseshoe magnet suspended at the breathing line would in a few days collect a surprisingly large amount of iron dust. On one occasion a magnet carried by a passenger on a ride of twenty minutes gathered a particle from the air which measured 2 mm. in length. Of three magnets hung up — one at the Grand Central Station of the subway, another in a dry grinding establishment, the third in an iron foundry — the subway magnet collected by far the most dust.

Eleven samples of subway dust were analyzed chemically, with results given in the following table:

TABLE I

Results of Chemical Analyses of Eleven Samples of Subway Dust

Date, 1905.	Place of collection.	Total iron.	Silica, etc., insoluble in acids.	Oil.	Volatile and organic matter.
		Per cent.	Per cent.	Per cent.	Per cent.
August 3	96th Street station	63.07	12.79	0.88	23.26
August 3	14th Street station	41.77	26.39	1.43	30.41
August 14	Grand Central station	67.35	12.65	1.23	18.77
August 18	23d Street station	54.36	20.50	0.99	24.15
August 17	Brooklyn Bridge station	45.72	21.79	1.97	30.52
August 21	33d Street station	69.66	12.34	0.91	17.09
August 21	Canal Street station	74.78	9.46	0.80	14.96
September 19	116th Street and Lenox Avenue station	66.69	13.84	0.96	18.51
September 19	Times Square station	68.42	7.45	1.00	23.13
September 20	18th Street station	59.84	17.94	1.43	20.79
September 20	28th Street station	62.58	16.28	1.42	19.72
	Average	61.30	15.58	1.18	21.94

A glance at this table shows that the average amount of iron in the dust was 61.3 per cent. The samples were collected from smooth,

clean surfaces upon which the dust had been allowed to settle from the air.

In addition to the iron particles, the dust contained bits of silica, cement, stone, fibers of wood, wool, cotton, silk and other textile materials, molds, and indistinguishable fragments of refuse of many kinds, resulting from the wear and tear of the subway and the clothing of the passengers. In fact, everything in the subway susceptible of wear contributed to the dust. In addition, refuse from the streets was carried into the subway by inflowing currents of air and by passengers.

Bacterial Composition of the Dust

On the whole the numbers of bacteria found in the dust of the subway were smaller than the numbers found in dust from the streets. The average obtained on analyzing thirty samples of dust from the subway was 500,000 per gram of dust. The average number found on analyzing 141 samples of subway air was 3,200 per cubic meter. These figures were about one-half as large as were found for the streets.

These numbers represent bacteria capable of growing on beef extract agar, of ½ to 1 per cent. acid reaction to phenolphthalein, at the temperature of the body and at such a rate that colonies could be counted at the end of forty-eight hours.

There was reason for believing that some of the bacteria in the subway were more harmful than those generally found outside. The absence of sunlight in the subway prolonged the life of the germs of some diseases. The pneumococcus, believed to be the cause of lobar pneumonia, was found by experiment to be capable of living twenty-one days in the subway as against four days in the streets.

The lack of enforcement of the ordinance against spitting and the frequency with which passengers and employees expectorated upon the tracks, platforms, and stairways increased the danger from tuberculosis and other respiratory diseases. The excessive crowding exposed the employees, particularly those holding the grades of guard and conductor, to a still greater danger of infection.

Sources of the Iron Dust

A large part of the metallic dust came from the wear of the brake shoes upon the steel rims of the wheels under the cars. It was calcu-

lated that one ton of brake shoes was ground up on every mile of the subway every month. In addition, there was some loss of metal from the rails, especially at the curves. So great was this wear that an especially durable steel was at length made to withstand it.

The rims of the wheels and the contact shoes which supplied the motors under the cars with electricity from the third rail contributed some weight of metal to the dust. Probably twenty-five tons would be a low estimate of the total weight of iron and steel ground up in the twenty-one miles of subway every month.

It must not be supposed that all of this great amount of ground iron floated in the air. Some of the pieces were so large that they fell immediately to the track and remained there. Others were raised only for brief moments by violent eddies produced by the trains. Large quantities were caught by the ties and broken stone ballast, which were continuously sprinkled with lubricating oil from the trains. Many of the particles were so greasy that they adhered firmly to whatever surfaces with which they happened to come in contact. The smallest and probably the freshest particles remained longest in the air. It was these which constituted the dust used in the analyses. It was these which were breathed.

Some dust was carried up into the streets by air currents which were forced out through the station stairways and blowholes by the trains. The trains also kept the dust in suspension in the subway. Had there been no trains the dust would have quickly settled from the air. This is shown by the bacteriological experiment recorded in Table II, in which the bacteria acted like exceedingly minute dust particles.

TABLE II

EFFECT ON THE NUMBERS OF BACTERIA IN THE AIR OF THE SUBWAY PRODUCED BY A SUSPENSION OF THE TRAFFIC WHICH LASTED ONE HOUR, NOVEMBER 11, 1905

Place of collection.	Time.	Microörganisms per Cubic Meter of Air	
		Bacteria.	Molds.
110th Street and Broadway station, north end, east platform. Soon after the collection of the first sample all trains stopped running	10.20ᵃ	1,300	0
	10.37ᵃ	750	0
	10.55ᵃ	400	0
	11.15ᵃ	250	0
Average	. .	700	0

Weight of Dust in Air

The average weight of dust in subway air was found to be 61.6 mg. per thousand cubic feet of air, or 2.25 mg. per cubic meter. This was somewhat more than was found in the streets under parallel conditions. The figures for the streets were 52.1 mg. per thousand cubic feet, or 1.83 mg. per cubic meter. The average for the subway is made up of the results of 146 analyses made at points and at times especially selected to give a correct knowledge of the normal conditions.

These analyses show that the total amount of dust in all of the air contained in the subway at any time from the 96th Street station to the Brooklyn Bridge was 3½ pounds. The dust was not quite evenly distributed through the air. There was more dust at express stations than elsewhere. At any given station there was more dust at the arrival ends of the platforms than at the departure ends. The difference was, however, very slight.

Weight of Dust Inhaled

The weight of dust which an employee took into his mouth or nose during the course of a day of ten hours could be computed from the results of the analyses just referred to. Assuming that 360 c.c., or 22 cubic inches, of air were taken in at each breath, and the employee breathed at the average rate of eighteen times per minute, the total quantity of air which passed into his lungs in ten hours was 6.86 cubic feet, or .19425 meter. Taking 61.6 mg. per thousand cubic feet as the weight of dust suspended in the atmosphere, it is found by calculation that an employee took into his nose or mouth 8.4 mg. of dust in ten hours. This is 3,066 mg. per year, or forty-six grains. It will be shown presently that only a small part of this could get into the lungs.

Reliable data are lacking to show the weight of dust which exists in the air of steel-grinding and other establishments where disease is produced by dust. Hesse found, some years ago, from 72 to 100 mg. of dust in a cubic meter of air in an iron foundry, and 14 mg. per cubic meter in the air of an iron mine.

THE DANGERS OF THE DUST

The possibility of the dust causing injuries to the eyes, to the skin, and to the respiratory apparatus was considered in this investigation;

but the condition of the throats and lungs of the employees received the largest share of attention.

Injurious Properties of Subway Dust

Inasmuch as dust may do harm in many ways, it may be well to describe briefly how the subway dust was regarded in its relation to the health of the subway employees.

1. *Chemical Composition.* — There was nothing about the chemical composition of iron particles to make them especially dangerous. They were not like lead and other poisonous dusts in this respect. If the subway dust had been composed of silica, its action would have been no different.

2. *Mere Quantity.* — The amount of the dust which was breathed was not great enough to be injurious solely on account of its bulk. In this respect the atmosphere of the subway was wholly unlike that of flour mills and cement mills. There the quantity was vastly greater.

3. *Bacteria.* — Dust when breathed may cause disease by carrying bacteria into the throat and lungs. This was a matter worthy of some attention, in view of bacteriological conditions in the subway already described. Particles of dust which carry harmful bacteria are among the most injurious kinds of dust.

4. *Mechanical or Physical Composition.* — Dusts whose consistency most resembles that of the organs which they invade are least harmful, so far as physical composition is concerned. The more jagged in outline and resistant in texture, the greater is the capacity of the particles to do harm. They irritate the delicate organs with which they come in contact, and so open the way for the entrance of pathogenic microbes. The most injurious of all dusts are composed of iron and steel.

So far as the subway dust was examined, the mechanical and bacterial conditions were of most interest.

Contributing Factors

Various factors predispose persons to respiratory dust diseases. Among these may be mentioned:

1. The existence of some respiratory disease already, as, for example, tuberculosis.

2. Predisposition to respiratory disease, whether this predisposition is inherited or constitutional, increases susceptibility.

3. A neurotic condition, in which the person anticipates or expects evil effects to follow the inhalation of a dusty atmosphere, increases the liability.

4. Exertion, requiring the breathing of unusually large quantities of air, bringing into the lungs more dust, must be recognized as a contributing factor. Mouth breathing may be included in this category.

5. Humid air, draughts, or an atmosphere in which rapid changes of temperature occur, contribute to the evil possibilities of dust.

6. An especially severe use of the voice is unfavorable.

Of all these factors, the amount of air breathed, the atmospheric changes, and the severe use of the voice seemed to be especially worthy of consideration.

Natural Defenses against Dust

In normal health the delicate structure of the lungs is protected in various ways against the entrance of dust particles from the air.

1. The nose and throat are themselves effective barriers. Only a very small proportion of the dust particles which enter the mouth or nose escape the moist and irregular channels which lead to the throat.

2. If a particle passes the mouth or nose, it is almost certain to be arrested by the mucous membrane of the trachea and lower air passages. Here myriads of moving cilia carry it to a point from which it can be removed by the conscious mechanism of coughing.

3. If the particles go further they enter the bronchioles, and from there pass to the air cells of the lungs.

4. When particles of dust reach the air cells they do not necessarily pass into the tissues. They do so only when they penetrate the endothelium with which these cells are lined.

Minute foreign substances may, however, be taken into the tissues before reaching the air cells of the lungs, especially when the normal activity of the mucous membrane is reduced. This is not uncommon among persons who breathe a dusty atmosphere. When particles are absorbed, whether in the throat or lungs, they generally enter the lymphatics and are retained by the nodes or filtering arrangements with which the lymphatic system is provided. Only in rare instances do foreign particles penetrate through the lymphatic system to the blood.

Infection through pathogenic microbes occurs when the protective barriers peculiar to the surfaces of the delicate mucous lining of the air passages become injured and the natural resistance toward them

is reduced. It is not improbably due largely to the constant irritation produced by dust upon the mucous membranes that respiratory diseases are so common among city dwellers.

Condition of Throats and Lungs of City Dwellers

Respiratory diseases are extremely common among persons who live in cities, pneumonia being frequently recorded as the leading cause of death, with tuberculosis following closely. Bronchitis and laryngitis are probably equally common, though less fatal, and pharyngitis and rhinitis still more prevalent. The minor affections not infrequently lead to the more serious.

When examined after death the lungs of city people can easily be distinguished from those of dwellers in the country, the bright, rosy color which is natural to the latter being changed to gray and sometimes to black by particles of soot and dust which have got into them from the air.

Mingled with the dust in the lungs of city dwellers are particles of iron. So great is the wear of iron, particularly from the wheels of vehicles, the brakes of street and elevated railway cars, and the shoes of horses, that it was impossible during this investigation to find a specimen of dust in New York which did not contain particles of metallic iron. Iron particles were collected from the surface of fresh snow on Liberty Island in the centre of New York Bay, a mile or more from the nearest land, thirteen days after an earlier snowstorm had covered the ground and kept dust from being blown from places where it had settled. White marble buildings in New York lose their original color in some situations within a year and become noticeably yellow. The amount of this iron dust which gets into the lungs is extremely small, but it can be detected by the microscope and by analysis.

It seems unnecessary to refer to other dusty particles which get into the lungs of city dwellers. The city streets are notoriously dusty. The dust consists of a pulverized mass of refuse in which building sand, ashes, and dry horse manure are conspicuous ingredients. The tendency of this dust is to settle to the earth, but excepting after rain or snowstorms it never is absent from the air. No building in New York is high enough to escape it. It is most objectionable in the crowded streets. At a single breath a pedestrian may take into his nose or mouth a greater quantity of dust than the average subway employee gets in a month.

Because of the peculiarly large amount of iron in the dust of the subway, the disease known as siderosis, which exists most commonly among metal polishers, knife grinders, and others engaged in working in metal, will now be given separate consideration.

Disease Due to Iron Dust

The inhalation of iron dust produces evil effects in three ways:

1. By diminishing the respiratory efficiency of the lungs through a loss in their elastic property.

2. By reducing the resistance of the organs to invasion by harmful bacteria.

3. By infecting the lungs through a transportation of disease germs to places favorable for their inoculation.

The earliest symptoms of siderosis are catarrh and bronchitis, but shortness of breath is pronounced by all authorities to be the most characteristic symptom. Eventually there follows what appears to be phthisis without the presence of tubercle bacilli. Yet genuine infective phthisis is the most common cause of death.

The cause of the unpleasant symptoms is sometimes not discovered until the exposure has been endured for years, depending upon the amount of dust in the air and the personal resistance to it. Even in fork grinding, the most dangerous of dusty occupations, the effects may be delayed for decades.

Probably a great many men engaged in dusty occupations pass their lives without suspecting the cause of the uncomfortable symptoms which they experience. There is no doubt that large numbers die from infectious pulmonary diseases who do not know that the breathing of excessively dusty air has led to their infection.

A writer in a recent periodical[1] has shown the startlingly high rate of death among various classes of metal workers in America who are apparently in ignorance of the peculiar danger of their occupation.

The death rate among steel grinders and others at Solingen, Germany, for the ten years 1885–95 is shown in the following table, in which the number of deaths from consumption is given in 1,000 deaths from all causes in Germany.[2]

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[1] *The Independent*, "A Story of the Death Claims." Andrew Hellthaler. December 27, 1906.

[2] Handbuch der Medizinischen Statistik. F. Prinzing. Jena, 1906, p. 489.

TABLE III

DEATH RATES FROM PHTHISIS AT SOLINGEN, 1885–1895

Age.	Grinders.	All males.
14–20	25.8	40.0
21–30	84.4	69.9
31–40	75.9	47.0
41–50	79.3	36.0
Over 50	68.7	25.8
Over 14	72.5	35.3

DESCRIPTION OF THE SUBWAY EMPLOYEES

Of the force of about 3,000 men employed by the Interborough Rapid Transit Company to operate the subway, about 800 were motormen, conductors, or guards upon the trains, about 800 ticket sellers, ticket takers, or porters at the stations, and about 1,400 switchmen, trackmen, mechanics, painters, engineers, or others engaged on the road, in the shops, power houses, or elsewhere. This investigation was restricted chiefly to the uniformed force, consisting of trainmen and station men.

All who occupied responsible positions with respect to the operation of the trains were examined physically by the company before they were employed, records being kept of their age, weight, height, respiratory capacity, sight, color sense, hearing, and heart action.

Absences from work for less than two weeks were not, as a rule, inquired into by the company, but in the event of serious sickness the men were examined medically before they were allowed to resume their work.

The employees sent by the company for examination were, at the author's request, forty-five motormen, forty-five conductors, and ten switchmen, this list including employees who had been longest on the road and whose work had kept them most closely under conditions similar to those experienced by the traveling public.

PHYSICAL APPEARANCE OF THE MEN

Nearly all of the men were of fine physique. Capacity to do hard manual labor was not demanded of the motormen, nor was it necessary

that the conductors should have more than ordinary strength; but inasmuch as men who were eligible to these grades were recruited largely from among persons who had had other railroad experience, it was to be expected that the physical standard would be high.

The men were all between twenty-one and forty-seven years of age. Their average height was 5 feet 8¼ inches, and their average weight 169 pounds. Their general appearance of health was excellent in fifty-two cases, good in thirty cases, and poor in only two cases.

Sixty-nine per cent. of the men claimed to be citizens of the United States. About half were city-bred.

Regular Duties of the Men

The motormen were from the regular force engaged in operating the trains. Their employment requires them to sit in a small compartment at the forward end of the car at the head of a train, where they operate a number of small hand levers. The position and duties of these men prevent them from doing any physical work. They are on duty, at most, ten hours each day.

The conductors serve in the capacity of guards, with some additional duties and responsibilities not of interest in this investigation. They are stationed between the first and second cars of the trains. They stand while at work and are required to make considerable exertion in opening and closing the heavy doors of the cars at the stations. In calling out the names of the stations amid the noise of the moving trains, the throats of the conductors are put to considerable strain.

The duties of the switchmen require them to couple and uncouple cars and switch them back and forth from one track to another at the yards and storage places. This force is largely composed of men who are in the line of promotion to motormen. Of the ten switchmen examined, four had been accustomed to railroading and two to indoor work exclusively.

Medical History before and after Entering Subway Employment

The men were asked for histories of themselves before and since entering upon their subway employment. In some cases the histories given were undoubtedly unreliable, and in a few cases the men were

evidently disinclined to talk; but in general their attitude was that of frankness and honest coöperation, and it seemed safe to put considerable reliance upon their statements.

Forty per cent. had a history of previous serious illness. Sickness had been divided proportionately between the three classes. The longest time lost through illness before going to work in the subway was five and a half months.

The average length of time that the men had worked in the subway up to the time of examination was 18.2 months. Only two men had been employed less than one year; these had been working ten months.

Thirty of the 100 men claimed to feel in better condition at the time of examination than when they first began to work in the subway; five felt in poorer health; sixty-five were unchanged. In fifty-four cases the weight had increased, this increase varying from 7¾ pounds to 15½ pounds. In eighteen cases there had been a decrease.

There were fifteen cases of illness reported to have occurred during the period of subway service. Of these only nine were affections of the respiratory apparatus. There had been three cases of tonsilitis and one case of bronchitis. In twenty-seven cases time had been lost from illness, but most of these illnesses were apparently of a trifling character. The conductors lost more time than motormen or switchmen.

Twenty-five men spoke of a metallic taste in the mouth, although this point was not mentioned by the others. In seventy-seven cases a decided and peculiar yellow stain was noted on the clothing moistened by perspiration. In fifteen cases these yellow stains were observable on the body, on underclothing, and on bedclothes even after bathing. Unusual drowsiness was mentioned in forty-six of the fifty cases inquired into.

In fifty-seven cases some sort of precaution, such as douching, was taken by the men to protect the nose and throat. In seventeen cases the nose and throat were douched every day.

RESULTS OF THE PHYSICAL EXAMINATIONS OF THE EMPLOYEES

Usually forty minutes were consumed in examining each man. The eyes, nose, and throat were first examined. The men were then required to strip to the waist and an examination was made of the organs of the thoracic and abdominal cavity. Measurements of the chest com-

pleted the examination. All observations and verbal information gathered from the men were noted in blank forms prepared for the purpose.

Examination of Principal Organs and Eyes

In nearly all cases the principal organs were in good condition. The average pulse rate was eighty-five, the highest 104, and the lowest fifty-six. The cervical glands were enlarged in sixteen cases.

The eyes were found to be slightly red or irritated in 39 per cent. of the men, but there was no congestion of the ocular conjunctiva. These conditions were no more prevalent in one class than in another.

Examination of the Upper Air Passages

Abnormal conditions found in the nose and throat differed only in degree from those usually found in dwellers in cities. Bony irregularities favor catarrhal conditions, and these were probably responsible for a good many of the cases of catarrh noted in these examinations.

In sixty-eight cases rhinitis was found. It was marked in two conductors and two motormen. Bony abnormalities of the nose existed in forty-five cases.

Forty-three of the men gave a previous history of catarrh. Fifty-four had catarrh at the time of the examination, twelve of whom considered that it had developed in the subway. Catarrh was slightly more prevalent among the motormen than conductors.

In seventy-seven cases the catarrhal secretion was black, brown, green, or dirty. There was no difference between the conductors, motormen, and switchmen in this particular. It was described as from the throat in all cases except one.

Pharyngitis occurred in seventy-two cases, of which fifty-three were acute or subacute. There was about as much pharyngitis among the motormen as conductors.

Laryngitis occurred in eight cases. A slight congestion was present in forty-seven cases.

Examination of the Lungs

Cough was present in twenty-eight cases. In only one case was it considerable. The chest configuration was "good" or "excellent" in eighty cases. It was "poor" in one case. The average circumference was 90.1 cm.; the lowest 80 cm.

Six per cent. of the men gave a family history of tuberculosis. There were five cases of bronchitis, three of which occurred among the conductors.

Slight emphysema, antedating the beginning of subway employment, occurred in two cases, both among conductors.

In thirteen cases slight pains were described. They were usually in the side or in the shoulder blade.

Dry pleurisy was present in fifty-three cases. It was axillary in forty-four cases; bilateral in seventeen cases; at the apex in twelve cases. It was distributed proportionately among the three classes of men examined.

Slight infiltration was present in thirteen cases. It was combined with pleurisy in eight cases.

There were five cases of slight fibrosis, all among the motormen. Three of these cases were described as doubtful; they were combined with pleurisy.

RESULTS OF ANALYSES OF SPUTUM, URINE, AND SWEAT

Laboratory tests were made of sputum, urine, and sweat with the object of throwing light upon the findings of the medical examinations.

The specimens of sputum were in every case stained and examined microscopically for tubercle bacilli. None was found. The presence of other bacteria and macerated epithelium from the mouth was frequently noted, but proved nothing of importance.

Specimens of sputum were examined for iron. After some experiment with different methods, the test adopted was the digestion of fresh sputum with strong hydrochloric acid and the addition of ammonium sulphocyanide. Particles of iron were frequently found, but it was impossible to say that they came from the lungs. In fact, in practically every case the specimens of sputum were only secretions from the mouth and throat. Satisfactory specimens from the bronchi could probably only be obtained, if at all, from the first expectoration of the early morning. Such specimens were requested of many of the men, but were never furnished.

A few samples of urine were examined for iron. The test employed was the same as that used in examining sputum. No evidence of iron was discovered. If present at all, the amount was extremely slight.

The sweat was examined for iron for the reason that the under-

clothing of many of the employees became stained yellow where the ordinary marks of perspiration might alone be expected. The color of these stains suggested iron. Apparently the stains came from iron dust dissolved upon the surface of the body and were not due to the condition of the sweat which was exuded from the skin. It was impossible to tell from the tests the source of the iron, but the fact that the bodies of most of the men contained iron particles, and the fact that the samples of sweat were not free from skin dirt, probably offers sufficient explanation of this condition.

RESULTS OF THE AUTOPSIES

Autopsies were performed upon the bodies of five employees and one other person killed in the subway during the year 1906. Four of the employees were trackmen; one had been employed six months, two two months, and one three months. In addition there were a switchman and a guard who had been employed a year each. All were of fine physique and below forty years of age. Most of the men were Italians and had come from Italy, where they had led an outdoor life.

The autopsies showed but few of the conditions which have been described in medical literature as characteristic of siderosis and other dust disease. The bodies were usually black with the peculiar dust of the subway, but a surprisingly small amount of this dust was found within. Iron particles were extremely hard to find in the trachea, bronchioles, and air cells of the lungs, notwithstanding the fact that the men had been run over and had probably gasped dusty air directly in through the open mouth while expiring. The air passages were invariably in a normal condition for city dwellers. The lymphatics contained metallic iron, but not in overwhelming amount. Particles of iron could now and then be found in the alveoli. With the iron particles were masses of other comminuted foreign matter, chiefly soot. The lungs had lost nothing of their spongy character. There were no bands of hard fibrous tissue running through them, as might be expected in siderosis. The walls of the bronchial tubes were not thickened.

A slight diffuse pleurisy was found in all cases, but iron particles did not exist in greater amount in the areas affected by this pleurisy than elsewhere. It is doubtful whether any of these pleurisies would have been discoverable before death.

The test for iron was essentially the familiar hydrochloric acid-and-potassium ferrocyanide method. The iron particles were also recovered by incineration.

The lungs of the subway employees autopsied contained somewhat more iron than a lung which was assumed to be normal, but this normal lung contained no metallic iron at all. Inasmuch as it is probable that the lungs of all persons who have lived a few months in New York contain iron particles in sufficient number to be detectable by the delicate method of analysis employed, it seems likely that the standard of comparison used was unreasonably severe. It may be said, therefore, that the autopsies threw no light either on the possibly evil effects of the dust or the prevalence of dry pleurisy. It would be equally unfair to assume that the dust was or was not injurious when breathed under the circumstances which surrounded these men. To settle this question would require many more autopsies, and it would be essential to have them performed upon the bodies of persons who had been longer exposed to the air.

POSSIBLE CAUSES AND CONSEQUENCES OF THE PLEURISY FOUND

That an unusually large amount of pleurisy existed among the subway employees had not been anticipated. It could not at once be explained. Its importance depended apparently upon whether it was due to dust or other conditions peculiar to the subway, and whether it was associated with some physiological condition still more serious.

It thus became desirable to inquire very carefully into the nature of the pleurisy and the conditions with which it was connected. These studies were too extensive to be fully reported here, but it seems desirable that some of their more essential features should be recorded.

Pleurisy, or pleuritis, as it is more accurately called, is an inflammation, or the result of an inflammation, of the pleural membrane which surrounds the lungs. This membrane has been likened to two sacks, which are partly in contact, one within the other. The inner pleura closely covers the lungs, while the outer lines the ribs and other tissues of the chest cavity. In health the surfaces of the two pleura are very smooth and glide over one another without perceptible friction as the lungs expand and contract in breathing. In pleurisy this smoothness disappears when the inflammation occurs. Eventually

the opposing surfaces become rough or adherent, a condition which can be detected when a stethoscope is applied to the outside of the chest wall. When the friction sounds are very pronounced, they are technically described as friction rubs, and when less so, crepitant rales.

Dry pleurisy, when chronic, is in most cases the result of the more common acute pleurisy with effusion, yet there is a primitive dry pleurisy which may occur without any of the symptoms which generally accompany pleurisy of the latter sort. Pain and a characteristic cough usually call attention to the existence of pleurisy. It was a remarkable fact, repeatedly noted with surprise by the medical examiners, that the subway employees rarely complained of pain, cough, or any other of the clinical symptoms of pleurisy.

The causes of pleurisy are believed to be generally microbic. Numerous harmful bacteria have been known to reach the pleura and set up inflammation. It is also a frequent complication in pneumonia and bronchitis and is associated to some extent with tuberculosis.

The frequency with which pleurisy is noted in autopsy in connection with other diseases of the respiratory organs is shown in Table IV, made from data kindly supplied by Professor F. B. Mallory, Associate Professor of Pathology, Harvard Medical School.

TABLE IV

FREQUENCY WITH WHICH PLEURISY WAS FOUND AT AUTOPSY IN 1,008 CASES OF OTHER RESPIRATORY DISEASES AT THE BOSTON CITY HOSPITAL, 1901–1905

Year.	Number of autopsies.	Number of cases of lobar pneumonia.	Number of cases of broncho-pneumonia.	Number of cases of acute pleurisy.	Number of cases of chronic pleurisy.	Number of cases of tuberculosis of lungs.	Number of cases of tuberculous pleurisy.
1901	177	32	37	34	110	44	. .
1902	213	24	40	12	94	23	1
1903	211	23	38	30	113	46	1
1904	200	24	72	35	117	45	1
1905	207	27	33	29	84	19	2
Total	1,008	130	220	140	518	167	5

This table shows that pleurisy existed, with other respiratory diseases, to the extent of 65.8 per cent. In most cases these other diseases were probably the inciting cause of the pleurisy.

In a way not yet entirely explained a sudden chill is an important factor in producing pleurisy. A slight dry pleurisy may follow almost

immediately upon exposure. The onset may resemble the onset of pleurisy with effusion, yet after a few days the symptoms disappear and no effusion occurs. A large percentage of the pleuritic adhesions seen after death are believed to originate in this way. Dry pleurisy is never fatal. Extensive adhesions, it would appear, might seriously interfere with the normal action of the lungs, but if it does so its effects are not serious. The importance of dry pleurisy depends chiefly upon the other diseases with which it is associated. People die of the diseases which have led to the pleurisy. In seeking to explain the condition of the subway employees, therefore, it seemed desirable to look carefully for respiratory affections.

Pleurisy among the Subway Employees

For purposes of study the records of the cases of dry pleurisy among the subway employees were gathered together into two groups, according to the friction sounds by which the pleurisy had been diagnosed. These were designated: Group I, Pleuritic Crepitations, and Group II, Pleuritic Rubs.

Cases of dry pleurisy in men who reported that they had experienced an attack of pleurisy or pneumonia before entering the subway were considered sufficiently accounted for and excluded from further study. This reduced the number from fifty-three to forty-five cases. Finally, one case, suspicious of a former attack of tuberculosis, was excluded, leaving forty-four cases of dry pleurisy unaccounted for.

The following data show where and to what extent friction sounds were heard and the condition of the nose and throat in each group:

Group I. Pleuritic Crepitations; Twenty-seven Cases

Distinctness of Crepitations		Location of Crepitations	
Very distinct	1	Apex	3
Distinct	12	Axilla	20
Slight	14	Apex and axilla	4
	27		27

With these the following conditions of the nose and throat were noted:

Rhinitis		Pharyngitis		Laryngitis	
Marked	2	Marked	0	Marked	1
Present	8	Present	1	Present	10
Slight	7	Slight	13	Slight	11
	17		14		22

The foregoing data show that the pleurisy was located mostly in the axilla. It was generally accompanied by pharyngitis and slight laryngitis, and rhinitis was present in about half the cases in Group I.

GROUP II. PLEURITIC RUBS; SEVENTEEN CASES

Distinctness of Rubs		Location of Rubs	
Very distinct	6	Apex	2
Distinct	11	Right axilla	5
Slight	0	Left axilla	10
	17		17

The following conditions of the nose and throat were noted in these cases:

Rhinitis		Pharyngitis		Laryngitis	
Marked	2	Marked	2	Marked	0
Present	3	Present	4	Present	1
Slight	11	Slight	10	Slight	11
	16		16		12

It will be observed that in Group II the pleurisy was located chiefly in the axilla, more often in the left than in the right side. It was in all but one case accompanied by slight rhinitis, and usually by pharyngitis and laryngitis.

There is considerable similarity between the data thus collated for the two groups. The friction sounds were found in the axilla as a rule. In more than half the cases there was congestion or inflammation of the nose and throat, this condition being very slight among the cases contained in Group II, in which the pleurisy was most marked.

A rather large amount of congestion and inflammation of the nose and throat existed among the employees who were apparently quite free from pleurisy. The following data illustrate this by showing the frequency with which laryngitis, pharyngitis, and rhinitis occurred among all the employees included in this study:

Number of men.	Employees.	Rhinitis.		Pharyngitis.		Laryngitis.	
		Cases.	Per cent.	Cases.	Per cent.	Cases.	Per cent.
47	Without pleurisy	28	60	29	62	24	51
44	With pleurisy	34	77	34	77	21	47
91	Difference	6	17	5	15	3	4

These studies showed that the condition of the men with and without pleurisy was in almost all ways identical, although among those who had pleurisy there was a little more rhinitis and pharyngitis but less laryngitis than among those who were without it.

Among the forty-four cases only one complained of sore throat, although seven said that their throats became slightly dry, and seven complained of hoarseness. In thirty-five cases the men spoke of a slight expectoration, thirty describing it as "black," "gray," "dark," "dirty," or "green," and three "white." Pain was mentioned in eight cases. It was always described as slight or occasional. In five instances the pain was in the shoulder, or axilla, and in two cases in the chest.

Normal Amount of Pleurisy among City Dwellers

In order to determine just how excessive was the prevalence of dry pleurisy among the subway employees, it seemed desirable to inquire how often this disease occurred among persons engaged in other occupations.

It was well to know that dry pleurisy in its milder forms frequently existed among persons in good health and that it was extremely rare to find a body after death free from a roughened or adherent pleura, but just how commonly pleurisy occurred to the extent noted among subway employees could not be determined from the literature of the subject. It had to be sought by special investigation.

Two hundred persons were therefore subjected to a physical examination of the lungs similar to that given the subway employees. The work was done by the same principal examiner. The men examined represented a large number of vocations and were chosen at random from among persons admitted to Bellevue Hospital for various causes.

It was found that dry pleurisy existed in the same degree as met with among subway employees to the extent of 14½ per cent. If allowance had been made for their medical histories, deducting old pleurisies, emphysema, and pneumonia from the count, as had been done in studying the records relating to the subway employees, this percentage would have been slightly reduced.

Among the 200 outsiders the pleuritic sounds were noted in the axilla in twenty-two cases and in the apex in seven cases. This was about the same ratio as found among the subway employees. The diagnostic signs noted were crepitant rales twenty-five times and fric-

tion rubs four times. Among the subway employees the occurrence of rubs was relatively more frequent; in other words, the pleurisy was more marked.

The cases of dry pleurisy found among men engaged in the various employments are shown in Table V.

TABLE V

OCCUPATIONS OF PERSONS FOUND TO HAVE DRY PLEURISY

Occupation.	Cases of pleurisy.	Occupation.	Cases of pleurisy.
Butcher	2	Street cleaner	1
Driver	3	Conductor	1
Laborer	4	Real estate	1
Iron worker	2	Janitor	1
Steam fitter	1	Poleman	1
Clerk	1	Gardener	1
Porter	1	Tunnel worker	1
Brass polisher	1	Laundryman	1
Horse clipper	2	Orderly	1
Cook	1	Oysterman	1
Roofer	1		
	19		10

Of these twenty-nine cases, six were among persons engaged in dusty work.

The records relating to the forty-four cases of pleurisy which had not thus far been explained were next examined in the hope of determining whether a knowledge of the previous occupations of the employees would throw any light upon their condition. This study proved more satisfactory than was anticipated. The leading facts of interest concerning the histories of the men are given in Table VI, which is divided into two parts in accordance with the severity of the pleurisy as indicated by the diagnostic signs, pleuritic rubs, and pleuritic crepitations.

TABLE VI

LENGTH OF SERVICE IN THE SUBWAY AND IN PREVIOUS OCCUPATIONS OF EMPLOYEES WITH PLEURISY

PART I. DIAGNOSTIC SIGN — PLEURITIC RUBS

No.	Subway Employment.		Previous Employment.	
	Grade.	Period of service.	Occupation.	Period of service.
1	Motorman	20 months	Locomotive fireman	6 years
2	Motorman	21 months	Conductor	11 years
3	Motorman	19 months	Locomotive fireman (5), motorman (3)	8 years
4	Motorman	19 months	Motorman	5 years
5	Motorman	15 months	Storekeeper	19 years
6	Motorman	21 months	Locomotive engineer	14 years
7	Motorman	21 months	Locomotive fireman (7), engineer (9)	16 years
8	Motorman	9 months	Motorman	10 years
9	Motorman	22 months	Locomotive fireman (9), engineer (5)	14 years
10	Motorman	17 months	Locomotive fireman (3), brakeman (3)	6 years
11	Motorman	22 months	Motorman	5 years
12	Conductor	20 months	Janitor	8–9 years
13	Conductor	16 months	Motorman	9 years
14	Conductor	16 months	Dry goods	8 years
15	Conductor	16 months	Motorman (1½), furrier (12)	13½ years
16	Conductor	26 months	Tamper	8 years
17	Conductor	16 months	Iron worker	17–18 years

Of the seventeen employees in which dry pleurisy was diagnosed by pleuritic rubs, six had, previous to their subway employment, been locomotive engineers, firemen, or brakemen, with an average period of service in these vocations of 10.1 years each. Of the remaining eleven, six had been motormen or conductors, with an average period of service of 8.6 years. Of the remaining five, one had been an iron worker for eighteen years.

TABLE VI — *Continued*

LENGTH OF SERVICE IN THE SUBWAY AND IN PREVIOUS OCCUPATIONS OF EMPLOYEES WITH PLEURISY

PART II. DIAGNOSTIC SIGN — PLEURITIC CREPITATIONS

No.	Subway Employment.		Previous Employment.	
	Grade.	Period of service.	Occupation.	Period of service.
1	Motorman	19 months	Motorman	3 years
2	Motorman	19 months	Conductor	10 years
3	Motorman	21 months	Locomotive fireman (3), storekeeper (6)	9 years
4	Motorman	15 months	Locomotive fireman (3), iron molder (5), steam fitter (11)	19 years
5	Motorman	21 months	Locomotive fireman (3), brakeman (4)	7 years
6	Motorman	9 months	Locomotive fireman (9), engineer (7)	16 years
7	Motorman	24 months	Motorman	20 years
8	Motorman	10 months	Locomotive fireman (18), motorman (4)	22 years
9	Motorman	16 months	Locomotive fireman (3), brakeman (3), conductor (3), yardmaster (3)	12 years
10	Motorman	22 months	Switchman	18 years
11	Motorman	22 months	Brakeman	10 years
12	Switchman	22 months	Office clerk	10 years
13	Switchman	16 months	Locomotive fireman	2 years
14	Switchman	15 months	. . . . .	. . .
15	Switchman	16 months	Expressman	5 years
16	Switchman	16 months	Conductor (trolley)	4 years
17	Conductor	22 months	Clerk	7½ years
18	Conductor	19 months	Elevator man	5 years
19	Conductor	24 months	Inspector (2), bartender (7)	9 years
20	Conductor	16 months	Conductor (5), salesman (14)	19 years
21	Conductor	16 months	Locomotive fireman (5), railroads (20)	25 years
22	Conductor	16 months	Machinist	12 years
23	Conductor	16 months	Conductor (trolley)	13 years
24	Conductor	16 months	Leather goods	7 years
25	Conductor	21 months	Clerk (1), contractor (19)	20 years
26	Conductor	16 months	Rubber goods (1½), truck gardener (5)	6½ years
27	Conductor	20 months	Fireman (2), grocery clerk (10)	12 years

Of the twenty-seven employees whose pleurisy was diagnosed by pleuritic crepitations, nine had been locomotive engineers, firemen, or brakemen, with an average term of railway service of 7.4 years. Of the remaining eighteen, seven had been motormen, conductors, or switchmen, with an average period of 10.4 years.

Here were twenty-eight men who had, previous to their subway work, been engaged in employments in which they were exposed to alternate heat and cold to a remarkable and unusual extent for an average of nine years each.

It seemed impossible to avoid the conclusion that the excessive amount of dry pleurisy was largely the result of forgotten or unrecognized attacks of pleurisy experienced by the men before they entered upon their subway work. Many circumstances favored this opinion, among which may be mentioned the absence of pain or other clinical symptoms of acute pleurisy, absence of pneumonia, tuberculosis, or bronchitis, and the excellent health records of the men since going to work in the subway. Furthermore, there was as much pleurisy among the motormen as conductors, while their exposure both to draughts and dust in the subway was quite different, the motormen shut up in their small compartments being well protected, and the conductors standing between the cars being much exposed.

Subtracting the twenty-eight cases of pleurisy thus explained from the forty-four cases which had been without explanation left sixteen cases finally unaccounted for. This was about the normal.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The principal conclusions reached by the author concerning the various subjects dealt with in this investigation follow:

1. The air of the subway, as judged by analyses and by careful studies of the health of the men, was not injurious.

2. The most objectionable feature of the air was the dust, which consisted chiefly of angular particles of iron. It was possible, also, that injurious bacteria might sometimes be associated with these metallic particles. Lack of strict enforcement of the city ordinance against spitting, and the want of skillful care in cleaning the subway, made this danger greater than it need be.

3. The odor and heat of the subway, although very disagreeable, were not actually injurious to health. The strong draughts and changes of temperature which occurred at the stations were the most objectionable atmospheric conditions, so far as health was concerned.

4. The employees submitted by the company for physical examination were a particularly robust lot of men. From their excellent

physique it appeared that they had been carefully selected, a fact which was explained when it was found that a large majority of the men had previously been engaged in railroading, where capacity to do hard manual labor was required. It was fair to assume that the employees examined represented a fair average of all those who came in close contact with the passengers, so far as resistance to disease was concerned.

5. There had been very little sickness among the employees during their period of subway employment, judging by the accounts which the men gave. No information with respect to this matter was obtainable from the operating company. Many of the men claimed to have gained weight since they had been working in the subway—a fact due, apparently, less to any peculiarly healthful property of the air than to the easier work required.

6. Most of the men spoke of drowsiness. This was perhaps to be explained by the comparative darkness of the subway, the monotony of the work, and fatigue to the eyes. The drowsiness was never sufficient to keep the men from performing their duties properly.

7. A large number of employees complained of yellow stains which came upon their underclothing, as they supposed, from their sweat. This caused considerable inconvenience. The stains probably resulted from iron particles upon the body which were acted upon by the sweat. Investigation excluded the probability that the sweat itself was discolored.

8. Careful physical examinations showed that an excessive amount of dry pleurisy, without pain or other physical discomfort, existed among the men. Pleurisy occurred to the extent of 53 per cent. among the employees and to the extent of 14½ per cent. among persons not engaged in subway work.

The cause of the dry pleurisy was not at first apparent, but upon investigation it appeared to have been in no way due to the subway. Nine per cent. of the men had medical histories which accounted for their condition, and 28 per cent. had worked for many years under conditions known to be favorable to the occurrence of this disease. The pleurisy had no visible effect upon the health of the men and was not likely to be injurious to them in the future.

9. Congestion and inflammation of the upper air passages were prevalent. Rhinitis and pharyngitis in acute or chronic form occurred in about 70 per cent. of the men examined. Laryngitis was less common, occurring in about 55 per cent. These figures are somewhat above the normal, considering the degree of severity represented. No

case of bronchitis was discovered. The prevalence of the minor respiratory affections noted was due, apparently, more to the previous employments of the men than to their present surroundings, although the excessive use of the voice required of the conductors seemed likely to aggravate these affections.

10. Analyses of the sputum, urine, and sweat of the men showed that iron dust was given off only in the sputum. This sputum was derived mostly from the mouth and throat, where most of the iron particles drawn in with the inspired air were caught.

11. The findings at autopsy threw no light upon the possibly evil effects of the dust. The men whose bodies were examined had worked too short a time in the subway for information of value in this direction to be obtainable. Iron was found in the lungs of all, but to an extent which had produced no evil consequences.

Recommendations

Certain specific recommendations seemed to be required, under the circumstances.

1. Care should be taken that persons employed in the subway are free from respiratory disease or a tendency toward it. This rule should be extended to all grades and positions and made to apply, also, to the women who operate the news stands.

2. Thorough physical examinations, especially of the respiratory apparatus and heart, should be made of all employees when they are first engaged and at yearly intervals subsequently.

3. While the dust was not proved to have produced harmful results, sanitary considerations require that it should be prevented as far as practicable from getting into the air. To this end (*a*) sand and sawdust should not purposely be scattered on the stairways and platforms, as at present; (*b*) sweeping and cleaning should be done in a more strictly sanitary manner, preferably in accordance with the recommendations of the Advisory Board of the Department of Health; and (*c*) investigations should be made to determine whether it is feasible to reduce or collect much of the iron dust.

4. The city ordinance against spitting should be enforced to the letter. Although some progress has already been made in preventing it, spitting is still practiced occasionally on the platforms and on the roadbed. Not only passengers but employees are offenders in this direction.

BOOK REVIEWS

Chemical Annual for 1907[1]

The scope of the book is indicated by the following table of contents: Properties of the Elements and Their Factors, Physical Constants of Inorganic and Organic Compounds, Calculation of Volumetric Analyses, Calculation of Gas Analyses, Specific Gravity Tables, Equivalents of Weights and Measures, Thermochemistry, Review of Chemical Literature and New Books.

The work is to a considerable extent a translation of Biedermann's "Chemiker-Kalender," which has been so long and favorably known; besides this source, tables have been condensed from Landolt and Börnstein's Physico-Chemical Tables, Poole's "Calorific Power of Fuels," and Lewkowitsch "Analysis of Fats, Oils and Waxes."

A valuable service has been rendered by giving a wider circulation to the American Standard Baumé Tables and the Standard Table of the Manufacturing Chemists' Association of the United States for sulphuric, nitric, and hydrochloric acids, and ammonia.

A feature of the book is a list of the more important articles which have been published between January 1, 1905, and June 1, 1906, which will be appreciated by the busy man.

The work will no doubt fill a want long felt by those not conversant with German, for a fairly comprehensive, low-priced reference book, and as such may be cordially recommended. A. H. Gill.

Flow of Air[2]

Mr. C. H. Kuderer has published a table of volumes of air passing through air-ways, giving the number of cubic feet per minute through

[1] Van Nostrand Chemical Annual for 1907. John C. Olsen, Ph.D., Editor. New York: Van Nostrand, 1907. Cloth, 496 + x pp. $2.50.

[2] Table of Volumes through Air-Ways; Cubic Feet per Minute. By C. H. Kuderer. Avonmore, Pa., 1907. 25 cents.

passages 1,000 feet long, and of various sizes from 1 square foot to 100 square feet, and at various pressures from $\frac{1}{10}$ inch W. G. to 5 inches W. G. A supplementary table gives the constants for making calculations for air-ways of greater length, and an example shows the method of using the tables. Unfortunately, no reference is made to the experimental data upon which the tables are based.

A Photographer's Pocket Book[1]

This is a compact little book for the pocket of the photographer afield. It contains a sixty-page section devoted to the manipulation of plates, films, and printing papers, with special reference to the Tabloid products of Burroughs Wellcome and Company; seventy-one pages suitably ruled for detailed notes of photographic exposures; a fifty-two-page diary; twenty pages for memoranda; a Wellcome exposure calculator, and a section containing data and instructions for its use.

The paper, though of necessity very thin, is suitable for the purpose; the book is well bound, and the exposure calculator gives excellent results when used as directed. The combination is altogether an attractive one.

Self-Propelled Vehicles[2]

Nothing can remind one more forcibly of the comparatively short time since automobiles were unknown to technical literature than a sentence from Clerk's well-known text-book, "Gas and Oil Engines," published in 1896. The author states that he "has carefully examined one of the gasoline motors then coming into prominence in connection with the recent trials of motor carriages in France, . . . and finds that the engine runs at constant speed, and the whole of the operations of the carriage are performed by means of levers, clutches, change wheels, and brakes. In the author's opinion, this carriage, ingenious

[1] Wellcome's Photographic Exposure Record and Diary for 1907. New York: Burroughs Wellcome & Co.

[2] Self-Propelled Vehicles. By J. E. Homans. Theo. Audel & Co., 1907. 6th ed., 600 pp., 400 il.

as it is, will not find much use in England. A carriage, however, using heavy oils (kerosene or petroleum) . . . would probably be very successful."

Eleven years have made all the difference between this experimental stage of automobile invention and the present condition, when factories are months behind their orders and the public throngs in hundreds of thousands to learn about the latest improvements in cars exhibited at the annual auto shows In the meanwhile at least a score of books have been written to describe the horseless carriage and its accessories, only to be made obsolete as the types of engines, transmissions, carburetors, and other details have been so frequently altered.

In one of the latest practical treatises the subject has been brought down to include the 1907 models. Although written in technical language, this book cannot fail to be clear to non-technical readers, and should prove interesting and instructive to amateur automobile enthusiasts, including, as it does, practical hints on adjustment and care of the mechanisms as well as descriptions of their construction. Several chapters are devoted to the running gear, including tires, wheels, steering apparatus, and springs. In connection with gasoline engines, a brief outline of the theory involved in design and in testing for power output is given. Electric and steam-driven vehicles are also treated; considering the limited number of steam cars in use, the space devoted to boilers and steam engines is unusually large. Particularly good chapters are given on transmission gears and differential driving.

J. C. RILEY.

BULLETIN OF THE BUREAU OF STANDARDS[1]

WITH the April number the *Bulletin of the Bureau of Standards* enters upon its third volume. An examination of the contents of this publication cannot but impress one with the high grade of scientific work being carried on in this government bureau. It is work distinctly of university grade, and is similar to that which has gone before in the two previous volumes.

The first article in the present number is by Dr. Edward B. Rosa

[1] Bulletin of the Bureau of Standards. S. W. Stratton, Director, Washington, D. C. Government Printing Office, April, 1907. Vol. III, No. 1, 161 pp., ill.

on the "Geometrical Mean Distances of Rectangular Areas and the Calculation of Self-Inductance." In this paper are discussed the corrections for insulated round wire and for the wires and layers in different parts of the coil. Tables are given of inverse tangents to nine decimal places of Stefan's equation, and a table of Napierian logarithms to nine places.

In a second paper Dr. Rosa discusses the "Compensated Two-Circuit Electro-Dynamometer."

Readers of Mr. Munsell's article in a previous number of the TECHNOLOGY QUARTERLY[1] will be interested in the article by Dr. P. G. Nutting on "The Complete Form of Fechner's Law." In this article the data for vision obtained by König and Brodhun (1888) are given in a table, and the mathematical properties of the curves are worked out, with the result that the general relation between visual sensation and stimulus is expressed by the equation

$$B = B_o \log [1 + P_m (L^c L_o^{-c} - 1)],$$

in which B = brightness, L = light expressed in meter-candles, L_o = threshold value, $P = \delta L : L$ = photometric function, P_m = minimum value of P, $B_o = \frac{1}{P_m c}$, c = a constant less than unity.

This paper is followed by one by Dr. Edward P. Hyde on "The Comparison of the Unit of Luminous Intensity of the United States with Those of Germany, England, and France." Tables are given containing summaries of the results obtained with the Harcourt, Hefner, and Carcel lamps in the national laboratories of the four countries named.

Dr. Hyde has another paper on "The Geometrical Theory of Radiating Surfaces, with Discussion of Light Tubes." In this are considered radiation from a cylinder, from a flat circular disk of 10 mm. radius, and from a uniformly radiating strip of infinite length.

Messrs. Frederick J. Bates and J. C. Blake, in a paper on "The Influence of Basic Lead Acetate on the Optical Rotation of Sucrose in Water Solution," give a curve showing the errors introduced in polarizations by various amounts of basic lead acetate in sugar solutions.

Messrs. H. N. Stokes and J. R. Cain have two papers, one on "The Colorimetric Determination of Iron," in which are described methods

[1] TECHNOLOGY QUARTERLY, March, 1905, 18, No. 1, p. 60.

for the extraction of ferric sulphocyanate, the form of the colorimeter, and the methods for concentrating the iron, for preventing the fading of the color, and special directions for concentrating traces of iron from various substances. In the paper on "Sulphocyanic Acid," these authors give a rapid method for preparing the pure acid, with an account of some properties of the solution, and they discuss the occurrence and characteristic reactions of isodisulphocyanic and isopersulphocyanic acids.

PROCEEDINGS OF THE SOCIETY OF ARTS

FORTY-FIFTH YEAR, 1906-1907

BOSTON, February 28, 1907.

THE 633d regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, February 28, at eight o'clock, about thirty-five persons being present. Professor Mott presided. The minutes of the last meeting were read and approved.

There being no further business to come before the meeting, the chairman introduced Mr. E. S. Cole, Consulting Engineer of New York, who spoke on "Water Works Losses, and the Use of the Photo-Pitometer."[1] Mr. Cole showed the relative losses under different conditions, and gave an interesting account of the recent investigations with the photo-pitometer in New York, with the object in view of detecting both natural losses and losses due to direct theft through meter by-passes. The lecture was illustrated with thirty lantern slides. After the thanks of the Society had been tendered the speaker by the chairman, the meeting adjourned.

BOSTON, March 14, 1907.

The 634th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 14, at eight o'clock, about fifty persons being present. Professor C. H. Peabody presided. The minutes of the last meeting were read by the Secretary and approved.

There being no further business to come before the meeting, the chairman introduced Professor A. H. Sabin, of New York, who spoke

[1] Printed in full. See pp. 141-161.

on "Paint as a Preservative Coating." Professor Sabin's long experience in this line of work, both theoretical and practical, as a chemist and a manufacturer made his address of much interest. The thanks of the Society were extended by the chairman, and the meeting adjourned at 9.30 o'clock.

BOSTON, March 28, 1907.

The 635th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, March 28, at eight o'clock. Professor Charles R. Cross presided. The minutes of the last meeting were read and approved.

The chairman introduced Dr. L. A. Bauer, Director of the Department of Research in Terrestrial Magnetism of the Carnegie Institute, Washington, D. C.

Dr. Bauer gave a most interesting account of the work in magnetic survey[1] done both by the Coast and Geodetic Survey and by the Carnegie Institute. He showed charts of the work already done, and briefly referred to the magnetograph records of the San Francisco earthquake, showing the absolute agreement with the seismograph, and in many instances their greater sensitiveness. About forty-five persons were present. The chairman extended thanks to the speaker in behalf of the Society, and the meeting adjourned at 9.30 o'clock.

BOSTON, April 11, 1907.

The 636th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 11, at eight o'clock, and was called to order by Dr. Robert P. Bigelow. The minutes of the last meeting were read and approved.

Hon. Willard Howland, of Boston, was introduced and spoke on the Cape Cod Canal. Mr. Howland reviewed the history of Cape Cod Canal projects from the earliest days. He clearly showed the need of such a canal, both from a commercial and a humanitarian point of view, and showed the advantages over all others of the Sandwich-

[1] Printed in full. See pp. 170–186.

Buzzard's Bay route, which has been chosen for the present location. The large attendance of one hundred indicated the interest taken in the subject. The meeting adjourned at 9.30 o'clock, after the thanks of the Society had been tendered the speaker.

BOSTON, April 25, 1907

The 637th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, April 25, at eight o'clock. Dr. Robert P. Bigelow presided. The minutes of the previous meeting were read and approved.

The chairman introduced Mr. Frank M. Gilley, who spoke on "Trade Instruction in Holland, and the Instrument Makers' School in the University of Leyden." Mr. Gilley has made a careful study of this school, and his long service as a teacher made his comments and observations of especial value and interest. Mr. Gilley brought out the differences between trade schools in Holland and in our own country, and spoke with much interest of the results obtained by their methods. From these schools a lad is graduated at fifteen or sixteen years of age, with a trade which makes him self-supporting at once. A subsequent course at the Instrument Makers' School puts him in a position to act as an amanuensis at various colleges both at home and abroad. Their ability to make and repair all sorts of apparatus makes them especially valuable assistants.

The thanks of the Society were extended to the speaker, and the meeting adjourned at nine o'clock.

BOSTON, May 9, 1907.

The 45th annual meeting and 638th regular meeting of the SOCIETY OF ARTS was held in Room 22, Walker Building, on Thursday evening, May 9, at eight o'clock, about one hundred and forty persons being present. The President, Dr. Henry S. Pritchett, was in the chair. The minutes of the last meeting were read and approved.

The Nominating Committee presented the following nominations for Executive Committee: Colonel Edmund H. Hewins, Mr. James P.

Munroe, Mr. Charles J. H. Woodbury, Dr. Robert P. Bigelow, Mr. William Lyman Underwood. The Secretary was empowered to cast one ballot for these gentlemen, which was done, and they were declared elected.

Walter S. Leland was nominated for Secretary for the ensuing year and was duly elected.

The report of the Executive Committee was presented by Colonel Edmund H. Hewins, chairman of the committee, and was accepted.

There being no further business to come before the meeting, the President introduced Mr. W. R. Warner, of Cleveland, Ohio, who spoke on "The Panama Canal." Mr. Warner visited the canal zone with the Congressional Committee which reported in favor of the lock canal.

The speaker showed about seventy-five lantern slides taken at various points of interest during the trip, clearly illustrating the condition of work at the canal. Several maps were thrown upon the screen showing the route, and the principal difficulties attending the construction both of a sea level and a lock canal were briefly described. Slides were also shown in which appeared the old steam shovels left by the French, some of which are in active operation, although most of them are being rapidly replaced by modern steam shovels. Mr. Warner's address gave an insight not only into the active work of construction, but also into the hospital service, views of which were shown, as were views of the engineers' quarters.

The President extended to the speaker the thanks of the Society, and the meeting adjourned at 9.30 o'clock.

WALTER S. LELAND, *Secretary.*

REPORT OF THE EXECUTIVE COMMITTEE OF THE SOCIETY OF ARTS FOR THE YEAR 1906–1907

BOSTON, May 9, 1907.

From time to time it is well to pause to consider the objects of our endeavor and how far we are attaining them. In the "Objects and Plan of an Institute of Technology" (Edition 2, 1861), President Rogers points out the connection between industrial progress and an enlarged acquaintance with the objects and phenomena of nature and with physical laws, and he speaks of the benefit which the most enlightened communities of Europe have obtained from this practical coöperation of education and the arts by the establishment of museums, societies,

and colleges of technology. He says: "With the view of securing the great industrial and educational benefits above alluded to, it is proposed to establish, on a comprehensive plan, an institution devoted to the practical arts and sciences, to be called the Massachusetts Institute of Technology, having the triple organization of a society of arts, a museum or conservatory of arts, and a school of industrial science and arts."

It will be seen that in the plan the SOCIETY OF ARTS was placed first, and in regard to it President Rogers says that "under the first of these characters" the Institute would form itself into a department of investigation and publication intended to promote research in connection with industrial science by the exhibition at the meetings of the society of new mechanical inventions, products, and processes, by written and oral communications and discussions, as well as by more elaborate treatises on special subjects of inquiry. Another line of activity proposed was the publication of a series of reports exhibiting the conditions of the departments of industry, with the progress of practical discovery in each and the discussion of the scientific questions involved. In order to carry out these plans for publication, it was proposed to found a journal, which, it was hoped, would be a powerful means for advancing the interests of the industrial arts and practical education.

With these plans the SOCIETY OF ARTS was founded, and it is with these objects in view that we have continued our activities until the present day. Advance in complexity and specialization of the various arts and sciences have resulted, however, in the formation of many special societies and in the publication of journals devoted to narrow lines of science and industry. There still remains, however, in every community the need of bringing to the attention of those who are not specialists the advances in arts and sciences which may have an influence upon the life of the people. This function may very well be filled for Boston by the SOCIETY OF ARTS. That we are accomplishing this object to some extent is shown by the gratifyingly large attendance at our meetings.

We have in the TECHNOLOGY QUARTERLY a journal which aims to fulfill the objects of the founder in regard to publication. This is done in two ways: first, by printing the Proceedings of the SOCIETY OF ARTS, and so far as possible publishing in full the communications that have been presented to the Society; second, by publishing original papers, giving the results of investigations carried on in the laboratories

of the Institute. In fulfilling the second function the TECHNOLOGY QUARTERLY is hampered by two circumstances, the most serious of these being that the investigators generally desire to publish their results in journals devoted especially to the sciences or arts to which they appertain. In order that the TECHNOLOGY QUARTERLY might be more truly representative of the work done in the Institute, a special committee of the Faculty and the Board of Publication, sitting as a joint committee, recommended the following resolution:

That in future every member of the instructing staff be requested to send to the Editor of the TECHNOLOGY QUARTERLY a full and exact title of every volume or paper published by himself as soon as this appears. With such title he shall also be requested to send a concise and comprehensive abstract or description of the volume or paper, and if possible a copy of the same as printed. Some papers might, perhaps, be reprinted in the QUARTERLY, but in general only the title and abstract will be given.

This was adopted by the Faculty, and in coöperation with the Editor the Faculty Committee on Publications have sent out circulars in pursuance of the above resolution, and this department of titles and abstracts will appear for the first time in the TECHNOLOGY QUARTERLY for June, 1907.

The second difficulty is that lack of sufficient funds makes it impossible to print in full the results of many investigations, which consequently appear elsewhere.

During the past year the Editor has been fortunate in securing an unusually large number of papers read before the Society for publication in the QUARTERLY, and also a number of papers presented to classes of students by distinguished visitors. Besides these, several of the departments have made valuable contributions, and the book reviews continue to be an interesting feature.

During the year there have been thirteen lectures delivered before the Society, as follows:

October 28, 1906. Dr. George W. Pierce, "The Wave Lengths in Wireless Telegraphy."

November 8, 1906. William Lyman Underwood, "The Work of the River Drivers in the Maine Woods."

November 22, 1906. Dr. George A. Soper, "The Air of the New York Subway."

December 13, 1906. A. E. Brown, "The Application of Hoisting Machinery to Shipbuilding."

December 27, 1906. Richard L. Humphrey, "The California Earthquake."

January 10, 1907. H. E. Warren, "The Governing of High Pressure Water Wheels."

January 24, 1907. Dr. Walter E. Winship, "Storage Battery Regulations."

February 14, 1907. F. L. DuBosque, "The Marine Interests of a Railroad."

February 28, 1907. Edward S. Cole, "Water Works Losses, and the Use of the Photo-Pitometer."

March 14, 1907. Professor A. H. Sabin, "Paint as a Preservative Coating."

March 28, 1907. Dr. L. A. Bauer, "Recent Results of Terrestrial Magnetic Observations."

April 11, 1907. Hon. Willard Howland, "The Cape Cod Canal."

April 25, 1907. Frank M. Gilley, "Preparatory Trade Instruction in Holland, and the Instrument Makers' School in the University of Leyden."

May 9, 1907. W. R. Warner, "The Panama Canal."

The meetings have been advertised, with two or three exceptions, in the *Saturday Evening Transcript* on the Saturday preceding the lecture, but it is questionable if the attendance has been largely increased in this manner.

The attendance at the meetings has been comparatively good, the smallest number about twenty-eight and the largest one hundred and forty. Sixty seems to be the average attendance.

The membership of the Society has been decreased in the past year by ten. One new member has been elected and one cannot be found, no address being known. At present there are on the books of the Secretary three hundred and six names. Of these, fifty-four are in arrears to the extent of two years or more, the sum total of the delinquent dues amounting to $774. Since September, $921 have been collected — $729 dues of the current year and $192 arrears, varying in sums from $6 to $24. A personal letter of appeal has been sent to each of the delinquents, and it is believed that persistent efforts will result in the collection of at least half of the amount still due.

EDMUND H. HEWINS, *Chairman.*

PUBLICATIONS[1]

Biology, and Sanitary Research Laboratory and Sewage Experiment Station

E. B. Phelps.—The Prevention of Stream Pollution by Strawboard Waste. Water Supply and Irrigation Paper No. 189. United States Geological Survey, Washington, D. C., 1906.*

W. T. Sedgwick.—The Expansion of Physiology. Vice-Presidential Address, A. A. A. S., Section K, Physiology and Experimental Medicine. *Science,* N. S., Vol. XXV, No. 635, pp. 332–337, March 1, 1907.*

An address drawing attention to the recent remarkable development of the physiological side of general biology and its increasing influence upon modern thought and affairs. The theory is advanced, in explanation of the comparative neglect of physiology between 1860 and 1890, that this was due to the almost universal concentration of biological work and thought upon Darwinism and its corollaries.

Chemistry and Chemical Engineering

W. H. Walker.—An Instructive Laboratory Experiment in Applied Chemistry. *Proceedings of the American Electrochemical Society,* Vol. IX, p. 23, May, 1906.*

Civil Engineering

C. B. Breed (with G. L. Hosmer).—Principles and Practice of Surveying. New York: Wiley & Sons, September, 1906.*

G. L. Hosmer.—See C. B. Breed.

G. F. Swain.—Engineering Education, an Informal Discussion at the Annual Convention, June 27, 1906, "What Is the Best Preparatory Education for the Civil Engineering Profession?" "Is Technical Training the Best Education for Executive Work?" *Transactions of the American Society of Civil Engineers,* Vol. LVII, pp. 141–149 and 177–180.

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[1] In order that the extent of productive work carried on at the Institute may be better known, it is designed to publish quarterly a list of the publications of the officers and students of the Institute, together with abstracts when possible. In this list the publications are arranged alphabetically by departments and then alphabetically by authors.

The asterisk after the title indicates that a copy of the publication has been placed in the library of the Institute.

DRAWING AND DESCRIPTIVE GEOMETRY

C. L. Adams.—Notes on Descriptive Geometry, Part I. Boston: George H. Ellis, February 15, 1907.*

ELECTRICAL ENGINEERING

G. C. Shaad.—Abstracting Engineering Papers. *Electric Journal,* Vol. IV, p. 83, February, 1907.*

ENGLISH

C. H. Collester.—Notes on the "New England Short O." *Modern Language Notes,* Vol. XXII, p. 80, March, 1907.*

This article calls attention, for the first time, to certain phonetic properties of a semi-dialectic sound of *O*, heard chiefly in New England and hence known as the "New England short *O*." Some analogies and uniformities in the usage are pointed out.

GEOLOGY

D. W. Johnson.—Drainage Modifications in the Tallulah District. *Proceedings of the Boston Society of Natural History,* Vol. XXXIII, p. 211, February, 1907.*

D. W. Johnson.—River Capture in the Tallulah District, Georgia. *Science,* N. S., Vol. XXV, p. 428, March 15, 1907.*

Both papers deal with the capture of the former head waters of the Chattahoochee River by the Savannah River, the capture having taken place near Tallulah Falls, in northeastern Georgia. The longer paper presents a full account of the whole problem, reviewing the previous writings on the subject, giving a brief account of the general geology and physiography of the southeastern United States, and discussing in greater detail the geology and physiography of the Tallulah district. It is shown that many peculiar topographic features exist in the district, which demand some rational explanation. A deductive study of river capture is then made, in order to determine what features would result from the capture of one stream by its neighbor. It is found that the features which ought to result from such capture are precisely those which do occur in the Tallulah district. Strong presumption is thus given in favor of the Savannah-Chattahoochee capture, suggested by some geologists but doubted by others. Conclusive proof that the capture did occur is then offered, based on the finding of old, stream gravels along the former course of the upper Chattahoochee, where no river now flows. The evidence afforded by the distribution of the fresh-water shells, urged by some in support of the capture theory, is examined but found inconclusive, although the fact of capture is well established on other lines of evidence. Alternative theories to account for the features of the Tallulah district are examined, but do not appear satisfactory.

The shorter paper presents an outline of the argument, but deals more especially with the principal evidences of capture and the inconclusive character of the argument based on the distribution of the fresh-water shells.

Mechanical Engineering

G. Lanza.—Some Tests of Reinforced Concrete Beams. *Proceedings of the American Society for Testing Materials,* Vol. VI, 1906, Philadelphia, Pa.*

G. Lanza.—Memoirs of Deceased American Investigators Who Have Contributed in a Marked Degree to the Advance of the Testing of Materials. *Proceedings of the American Society for Testing Materials,* Philadelphia, Pa., Vol. VI, 1906.*

Mining Engineering and Metallurgy

H. O. Hofman (with R. P. Reynolds and A. E. Wells).—Laboratory Experiments in Lime-Roasting a Galena Concentrate with Reference to the Savelsberg Process. *Transactions of the American Institute of Mining Engineers,* April, 1907.*

H. O. Hofman (with W. S. Caypless and E. E. Harrington).—The Constitution of Ferro-Cuprous Sulphides. *Transactions of the American Institute of Mining Engineers,* April, 1907.*

Physics

L. Derr.—Photography for Students of Physics and Chemistry. New York: Macmillan, 1906.*

Research Laboratory of Physical Chemistry

W. C. Bray.—See A. A. Noyes.

A. A. Noyes (with W. C. Bray).—A System of Qualitative Analysis for the Common Elements. *Technology Quarterly,* Vol. XIX, No. 3, p. 191, September, 1906, and *Journal of the American Chemical Society,* Vol. XXIX, p. 137, February, 1907.

Institute Publications

Report of the President and Treasurer. *Bulletin of the M. I. T.,* Vol. XLII, January, 1907.*

Register of Graduates. *Bulletin of the M. I. T.,* Vol. XLII, March, 1907.*

Summer Courses, 1907. Boston, March, 1907.*

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Vol. XX. SEPTEMBER, 1907 No. 3

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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Vol. XX SEPTEMBER, 1907 No. 3

THE MARINE TYPE OF BEAM ENGINES[1]

By R. C. MONTEAGLE

Beam engines for the purpose of marine propulsion have not been discussed in detail very freely. This is somewhat remarkable when one considers their American origin and development, and is a matter of regret, as the subject is a highly interesting one and one which must prove of great value to the student.

The reason for this comparative absence of literature on a subject of such importance is probably to be found in the fact that the manufacture of these engines has been, and still is, monopolized by two or three establishments, these particular firms receiving orders from both the Atlantic and Pacific coasts, by reason of having in their possession the necessary drawings and patterns plus the experience in building the engines. This, taken in combination with the fact that the demand for this type of engine seldom at any time has exceeded the output capacity of these few favored shops, made it inadvisable that data and illustrations be given out for publication which might then be utilized by competitors.

I propose to give a general idea of the design of this type of engine, illustrated by some drawings made partially in detail.

Contrary to the belief of many, the beam engine is still being built occasionally for ferryboat propulsion and for river service. In all cases, whether these engines are equipped with surface condensers or

[1] A lecture delivered before the students of naval architecture.

jet condensers, they compare quite favorably in the matter of economy with compound engines The majority, however, are equipped with jet condensers and with air pumps of ample capacity. As a result, a vacuum as high as 28 inches has been obtained. When jet condensers are used the condensed steam and sea water are pumped overboard by the air pump, entailing a considerable loss of heat.

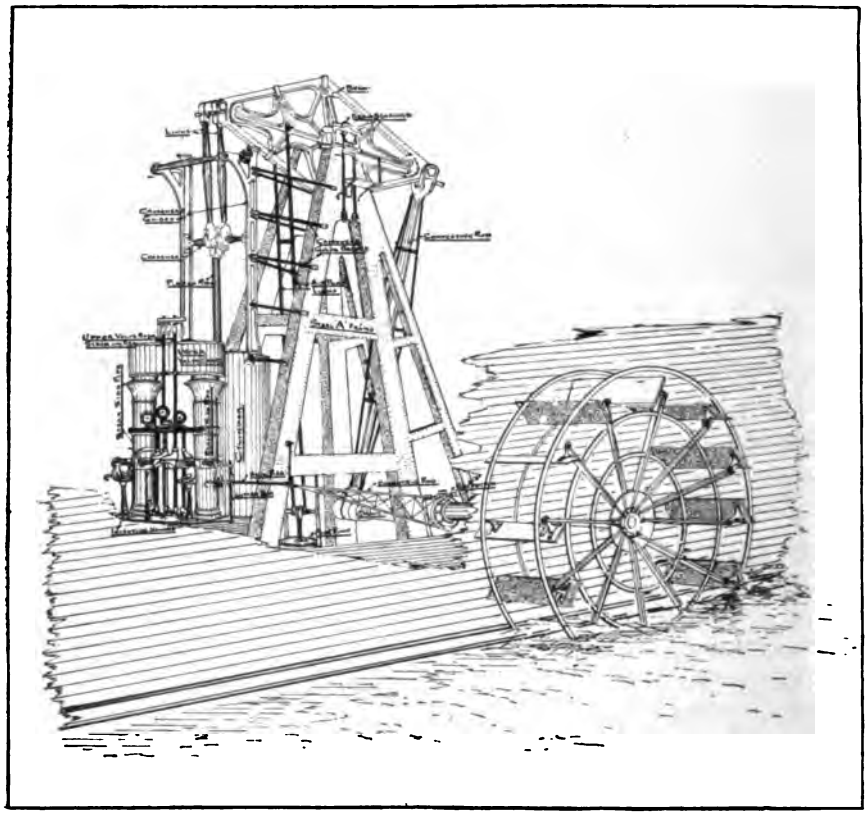

FIG. 1.—GENERAL ARRANGEMENT OF A BEAM ENGINE WITH STEEL A-FRAME

Boilers for single-cylinder beam engines are made to withstand a working pressure generally of fifty pounds per square inch. There have been instances where compound beam engines have been fitted in passenger steamers, the boiler pressure in such cases, of course, being raised. The cylinders are then arranged on one end of the beam, the connecting rod on the other. The high pressure cylinder

is placed next to the beam centre, or fulcrum, and has therefore less stroke than the low pressure cylinder. Practically no gain in economy over the old single cylinder was obtained in these cases, the economy, if any, being more than offset by the additional friction, initial cost, and subsequent cost of repairs.

As a consequence, beam engines for marine purposes, when they are built at the present time, are built with single cylinders and *generally* with jet condensers. This may easily be verified by a visit to any of our harbor ferryboats, one of which was built only last year.

Referring to Figure 1, an approximate perspective general arrangement of a beam engine is shown with steel A-frame. The great length of connecting rod is illustrated. This, however, is not abnormal in proportion to the stroke of the engine. In this drawing and the others to be thrown on the screen are shown only one steam eccentric and one exhaust eccentric. This I have done for the sake of simplicity.

All ferryboats and most other passenger steamers equipped with beam engines have two steam and two exhaust eccentrics, one set for going ahead, the other for going astern. In cases where there is only one ahead set of eccentrics the reversing is done entirely by hand, the gear being illustrated on another plate to be shown later. Short wipers on the hand gear shaft engage with lifting toes attached to the valve rods, these in turn being moved by a hand lever operated by the engineer. All beam engines are equipped with this hand gear, and when operating the engine near docks or making landings the hand gear is used for *either* going ahead or astern, the control being almost instantaneous.

I would call attention to the peculiar method of staying the crosshead guides, which is clearly shown in Figure 1. It is one which permits a certain amount of lateral movement, although not sufficient to cause trouble.

To the piston rod is attached a T-shaped crosshead which slides in vertical guides. This crosshead carries two links which connect to the pin on the end of the beam. From the other end is suspended the connecting rod, which is of a round cross-section, its greatest diameter being at the centre of its length. The extreme length of the rod renders it necessary to increase its diameter very materially at the centre, and, in addition to this, to truss it in the fore and aft direction. This truss is placed there principally to take up the excessive vibration, due to the variable compressive strains and to the oscillations of the rod, although the truss also adds materially to the strength of the rod.

Common dimensions for ferryboat engines are: diameter of cylinder, 52 inches; stroke, 12 feet, running about 550 feet piston speed. Taking the area of 52 multiplied by a possible initial pressure of fifty pounds per square inch, plus fourteen pounds for vacuum, we have a strain on one end of the beam of about 136,000 pounds. As the fulcrum is set in the centre of the beam, it follows that there is 136,000 pounds on the other end, the sum of these two being 272,000 pounds, or 136 tons. This load is transmitted through the pillow blocks to the gallows frame

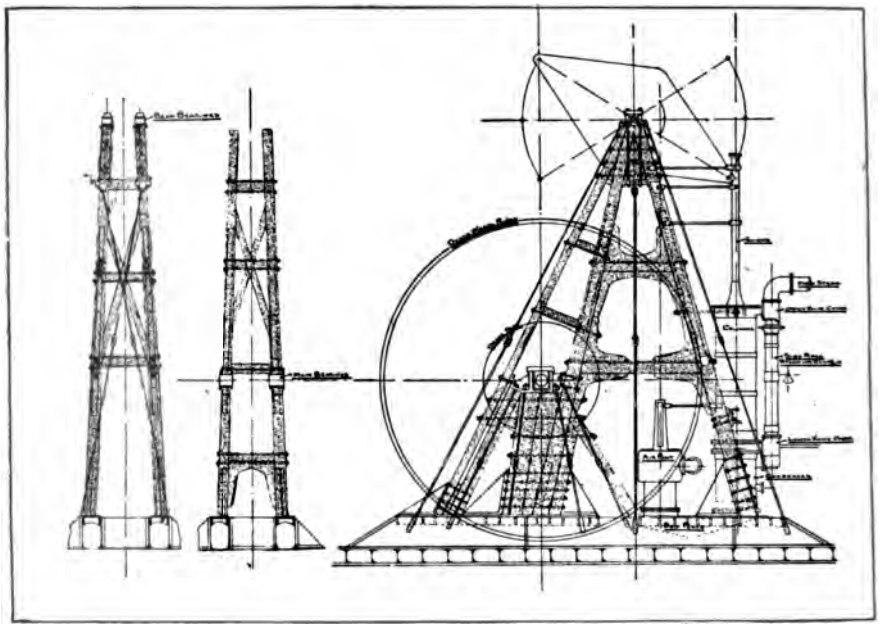

FIG. 2.—SHOWING A-FRAME OF WOOD

and through the gallows frame to the hull of the vessel, this being accomplished twice in every revolution of the engine, once in compression and once in tension. It is an extremely severe condition, but one which has been very satisfactorily met in the construction as indicated, or in a similar construction of wood.

During the past ten years feathering bucket paddle wheels have frequently been fitted in connection with beam engines, thus permitting the use of wheels of very much smaller diameter without loss of efficiency and at the same time reducing weight to a minimum.

Figure 2 shows the A-frame of the engine, or gallows frame, as it

is termed, constructed of wood. The frame is attached to the hull by means of plate brackets to deep girders running fore and aft, and of sufficient length to distribute the severe strains.

Wooden A-frames should be built of well-seasoned material thoroughly bolted and fastened, many well-fitted keys being driven between the timbers under the main bearings to prevent working and consequent loosening of the bolts. Long bolts with turn-buckles are fitted, connecting directly from the main and beam bearings to the deep keelsons. This is absolutely necessary, as the strains set up are alternately compressive and tensional every down or up stroke of the piston.

The gallows frame is now frequently constructed of steel, as shown in Figure 1, all the members being built up of plates and angles of box section. The gallows frame is connected to the hull framing, as shown. The condenser, with cylinder and steam chests superposed, rests on a bedplate connecting the two fore and aft girders. On the opposite end of this bedplate is placed the air pump, and through a channel way connecting the condenser and the pump flows the sea water combined with the condensed steam.

In practice it has been found that the air pump should have a capacity of from one-sixth to one-seventh that of the cylinder. This proportion should give a vacuum of about 27 inches if all joints are tight. The air pump is usually an iron casting lined with brass, and is worked from the beam. The foot valves and bucket valves are of pure rubber, with guards. Usually the main feed and bilge pumps are connected to the same crosshead which works the air pump, the stroke, therefore, being the same.

Figure 3 represents a cross-section of a vessel taken at the paddle wheels and showing the crank shaft in place. The method of supporting the outboard bearings of the wheels is illustrated, that is, by kingpost and stays. The deep girders in the bottom of the vessel to which the A-frames are attached are also shown connected by angle irons to the floors.

Reference should be made to the projecting guards with which side wheel steamers are almost invariably fitted. At a short distance from the bow the main deck begins to extend beyond the line of the hull, and the width of the projecting part increases until it reaches the outside line of the wheel housing. Aft of the wheels it gradually diminishes again towards the stern. The superstructure and upper decks follow approximately the same outline. Vessels of 50 feet beam

are frequently as much as 90 feet over the guards, giving 20 feet overhang. Screw steamers are now frequently constructed on this plan, a notable and recent instance being the new Parson's turbine

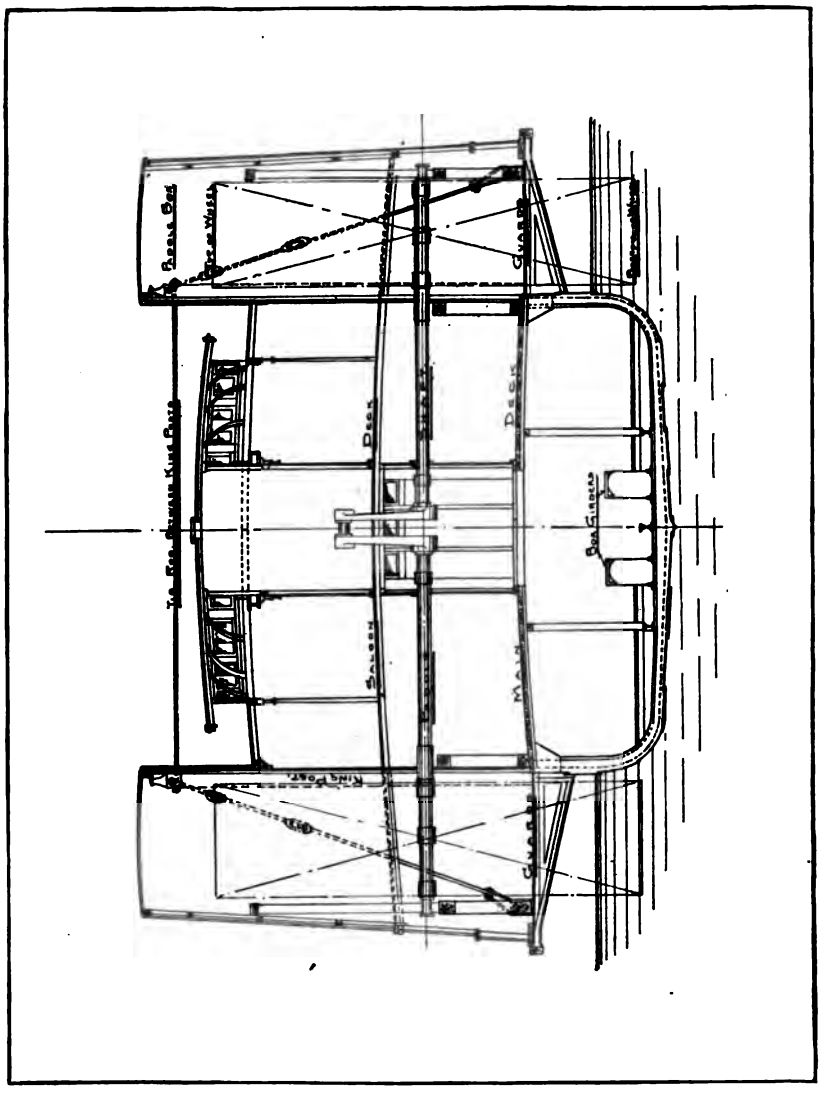

FIG. 3.—CROSS-SECTION AT PADDLE SHAFT

steamer *Governor Cobb*, now running from Boston and belonging to the Eastern Steamship Company. The old and still general method of supporting these guards is by means of diagonal struts connected

to the hull just above the load water line. In the *Governor Cobb* and many other sea-going vessels this has been modified. The frames and shell plating flare out from the normal beam at the water line to the extreme width at the guards, thus giving additional buoyancy and stability, and preventing the sea from striking upwards against the great flat surfaces of the guards, which must necessarily be a source of weakness and consequent danger. This weakness will undoubtedly be called to your attention should you ever make a trip on one of these vessels during heavy weather.

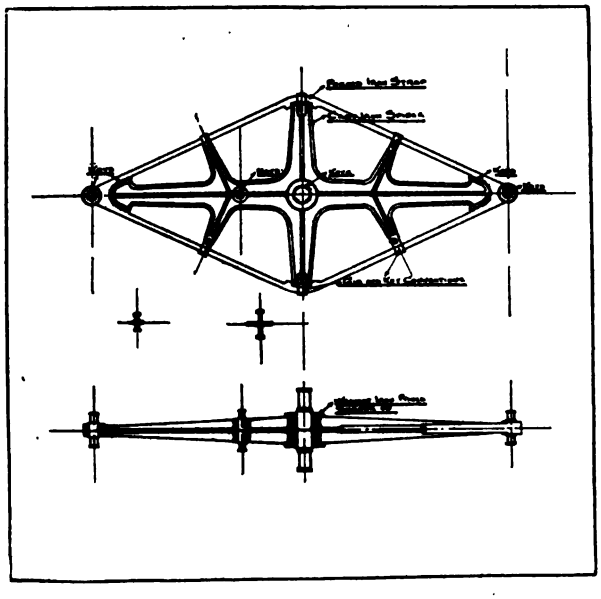

FIG. 4.—DETAIL OF BEAM

The principal object in having guards is to give deck room. In the case of the Hudson River passenger steamer *Mary Powell* and many others of the older type, the guards were utilized to support the boilers, the depth of the vessel under the main deck not being sufficient for this purpose. On the Pacific coast there are steamers with horizontal engines placed partly on these guards, each engine being entirely independent of the other, with an engineer on either side of the vessel. When required one engine goes ahead, the other astern, thus turning the vessel approximately in her own length.

Figure 4 shows the beam, which is made up of a cast-iron "spider,"

fitted carefully into a circumscribing band of wrought iron or mild forged steel, these two being bound together by many straps and keys, as indicated. The shaft and pins are held in position in the spider by four or more keys, the holes in the spider being bored out about .1 inch larger in diameter than the shaft or pins in each case. Wrought iron rings are then shrunk around the shaft hub on either side.

In making calculations for the strength of the beam, the whole strain is figured, of course, on the band. The fiber stress should be figured not to exceed 6,000 pounds per square inch, thus giving a large margin of safety and allowing for possible imperfections in the forging not visible on the surface.

Figure 5 shows the cylinder and cylinder heads, upper and lower valve chests, steam and exhaust side pipes, and jet condenser.

The valves are poppet valves, as shown in Figure 8, and it should be noted that the upper steam valves are larger in diameter than the lower, and that the lower exhaust valves are larger in diameter than the upper. The reason for this is the necessity of having a partially unbalanced valve, the difference in balance being in each case sufficient to close the valves when free.

The steel flat-plate expansion joints, shown between the upper steam chests and the tops of side pipes, perform their functions in a highly satisfactory manner, and it is very necessary that they should, the pipes being perfectly rigid and of cast iron. A leak in these joints rarely occurs, owing to the efficiency of this joint.

The temperature in the steam side pipe is that due to sixty-four pounds absolute, viz., 296°.8 F.; and the minimum temperature in the exhaust pipe is that due to, say, two pounds absolute, viz., 126.3 F., giving a possible difference of 170.5 F. Taking the length of the side pipes at 10 feet, which is quite normal, the coefficient of linear expansion for cast iron (of which they are invariably made) is .00000617. The increase in length of the steam side pipe over that of the exhaust in this case is, therefore, $10 \times 170.5 \times .00000617$ expressed in feet, which worked out will give an expansion of over $\frac{12}{100}$ of an inch. From this it is seen how absolutely necessary it is to have an efficient expansion joint. The principle upon which these expansion joints act is that of a diaphragm or flexible plate. Bonnets are placed on the fronts of the valve chests, so that the valves and valve seats may be put in position or removed, and also so that they may be examined. The injection water, as will be noted, impinges against the roof of the condenser, then

scatters and falls through the perforated plate, and in doing so breaks up and mingles with the exhaust steam, finally falling down into the channel connecting with the air pump.

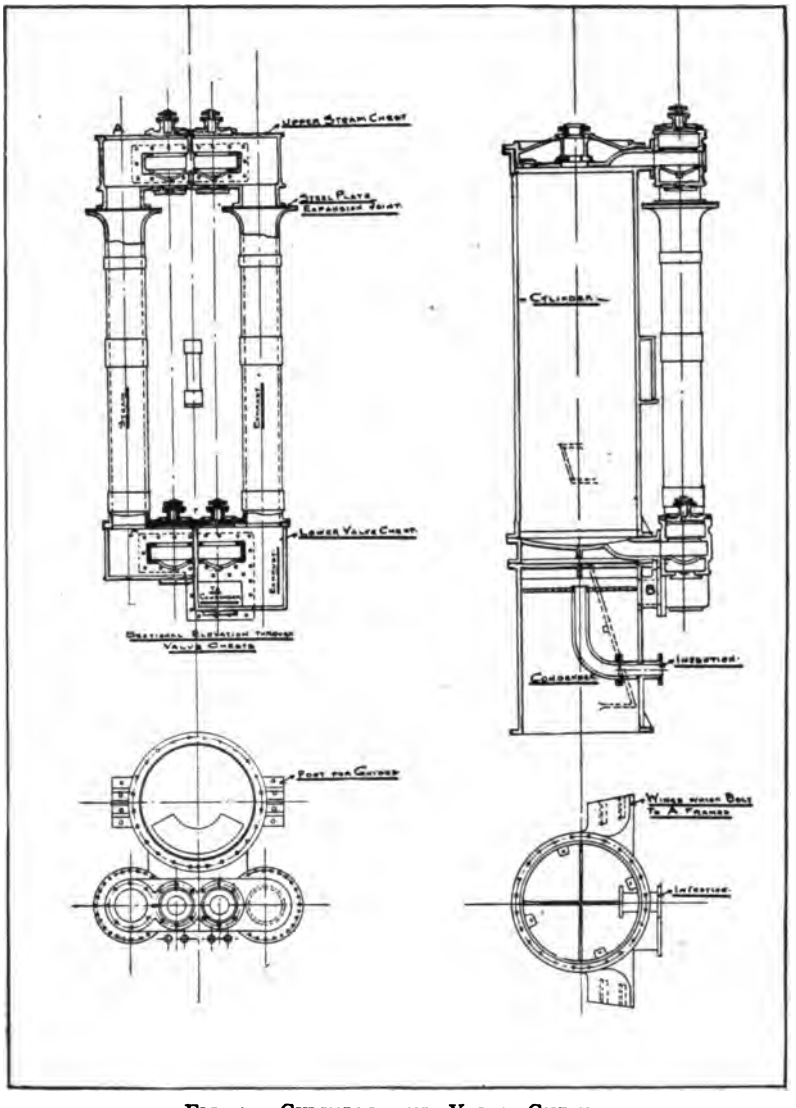

FIG. 5.—CYLINDER AND VALVE CHESTS

Figure 6 shows the general arrangement of the valve gear. You will note the foot lever C which operates the rods for throwing the hook rods D in or out.

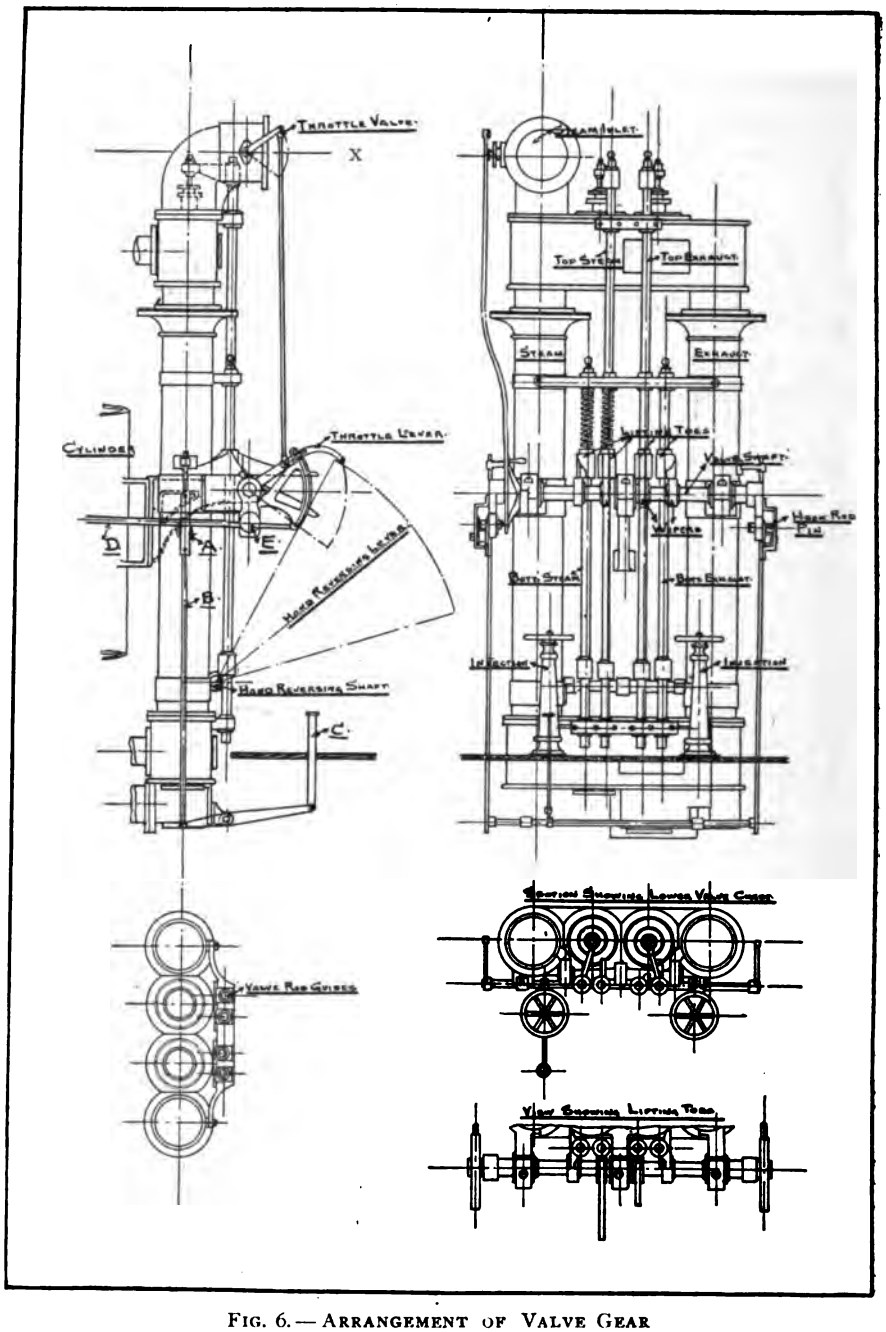

FIG. 6. — ARRANGEMENT OF VALVE GEAR

As I stated formerly, almost all beam engines constructed at the present time have a set of ahead and a set of astern eccentrics and rods. This drawing is made showing only one set. When it is desired to reverse the engine the foot lever is pressed down, forcing the rod B in an upward direction. This rod carries a small pulley A, which engages with the hook rod, lifting and holding it out of contact with the pin E, which is held firmly in the lever operating the valve shaft. The valve shaft is in two pieces, being cut in the centre bearing, one-

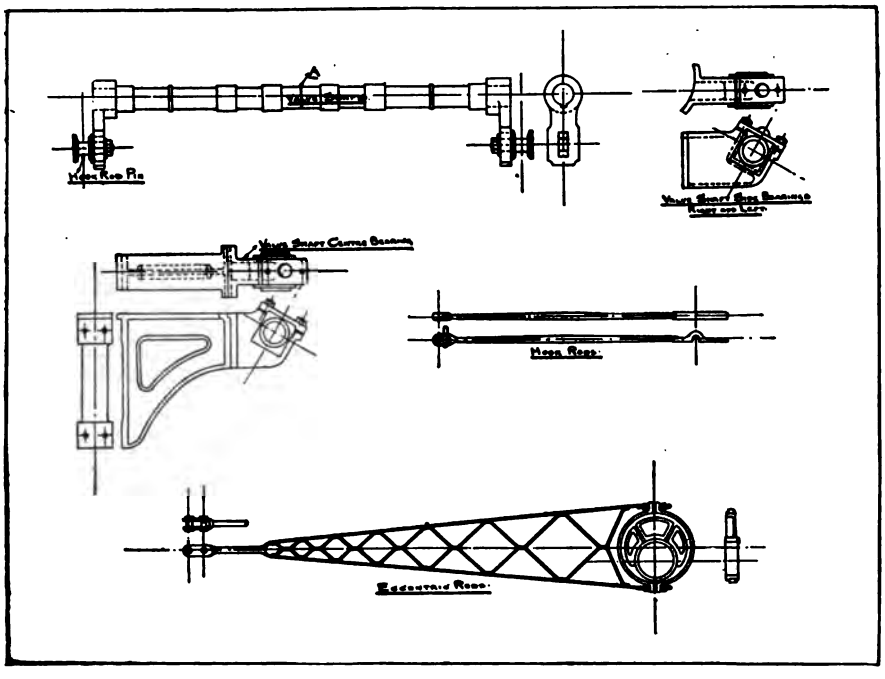

FIG. 7.—ECCENTRIC GEAR

half operating the steam wipers, the other half operating the exhaust wipers. The springs shown on the steam valves are placed there to cause a rapid closing of the valves. There are shown two stands for operating the injection valves. This is necessary, as there are always two injector valves fitted, one on the bottom and one on the side of the vessel. There is always a possibility of one strainer being rendered inefficient from various causes, and were there only one valve, in case of a stoppage to the strainer, it would be impossible to run the engine.

Figure 7 shows valve shafts and levers (the shafts being parted at

A), side and centre bearings for valve shaft, hook rods, eccentrics, and straps. The steam eccentrics are invariably given a greater travel than the exhaust eccentrics, although the steam valves have less lift than the exhaust valves, the object of this being to give a greater arc of travel to the steam wipers, so that the valves will open more rapidly.

Due to the extreme length of the eccentric rods, a truss method

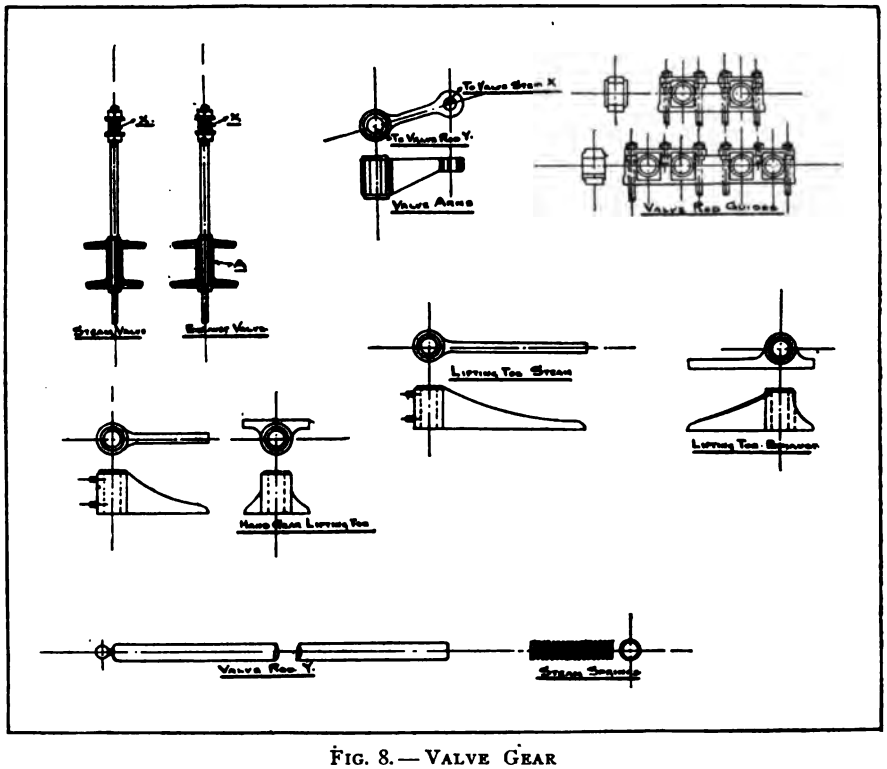

FIG. 8.—VALVE GEAR

of stiffening them has been adopted, as shown in the figure. It gives a fairly rigid construction with a minimum weight.

Figure 8 shows the steam and exhaust valves and stems, valve arms, valve rod guides, steam and exhaust lifting toes, hand gear lifting toe, valve rods, and springs. The lower steam valve being smaller than the upper, there is no difficulty in entering it through the upper valve seat. On the contrary, the lower exhaust valve being larger than the upper, it becomes necessary to part it at A, the lower part being put in place through the bonnet in the front of steam chest, the upper part being

put in place from the top, and finally the stem being put in place, holding the upper and lower valves securely together.

Figure 9 shows various positions of the wipers, lifting toes, and hook rods. At A the hook rod is disengaged and riding on the roller A, shown in Figure 6. At B the exhaust wiper is at extreme position, the valve being at its greatest opening. At the position C the steam valve is open, due to the amount of lead given. At D the steam wiper is at extreme position, the valve being at its greatest opening.

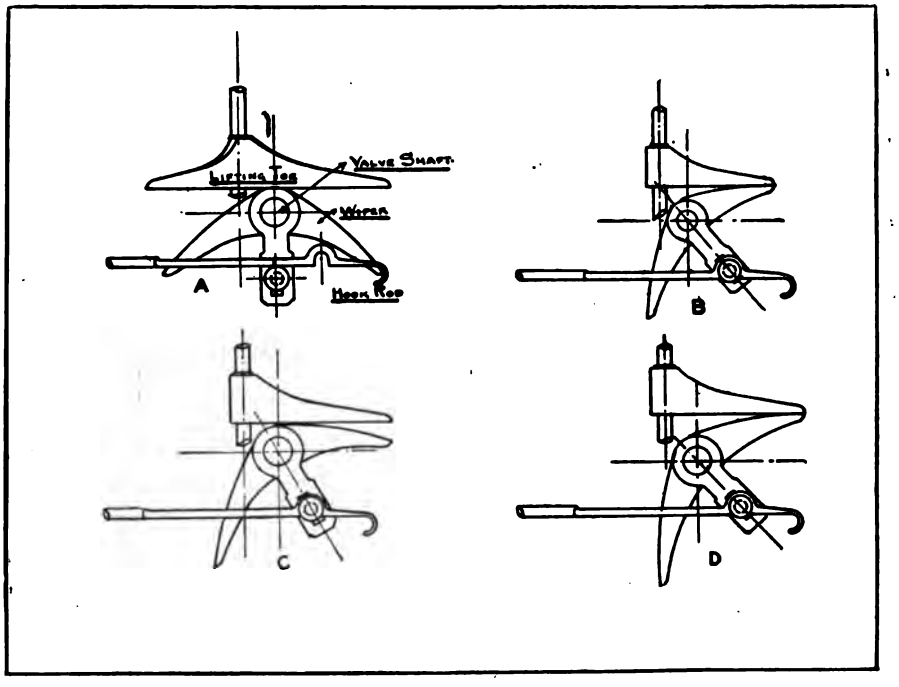

FIG. 9. — LIFTING TOES

Figure 10 shows the crank shaft with radial wheel in position, also a detail of crank pin. In placing this shaft in position in the boat, the bearings are installed first, next the shafts are placed in position minus the cranks. Finally the cranks are put in place, as they usually must be shrunk on in the vessel. A fire is then carefully built, the vessel being duly protected by asbestos and iron where required, and the shaft end of the crank is heated to a sufficiently high temperature, hoisted between the ends of the shaft, and slipped over the end of the shaft in its final position.

A very important point to remember in designing one of these shafts is that the dimension A must be greater than the dimension B or the crank will not go in place.

The paddle wheels have each three sets of radial arms, with tapered ends fitting into sockets in the cast-iron disks shown, these disks being keyed to the shaft. The hub of each disk is hooped by two wrought iron bands, and the arms are bolted to the disks. Each set of arms has two or three concentric rings of iron, spaced as shown in the figure. Midway between each set of wooden arms is a radial iron arm with T-ends

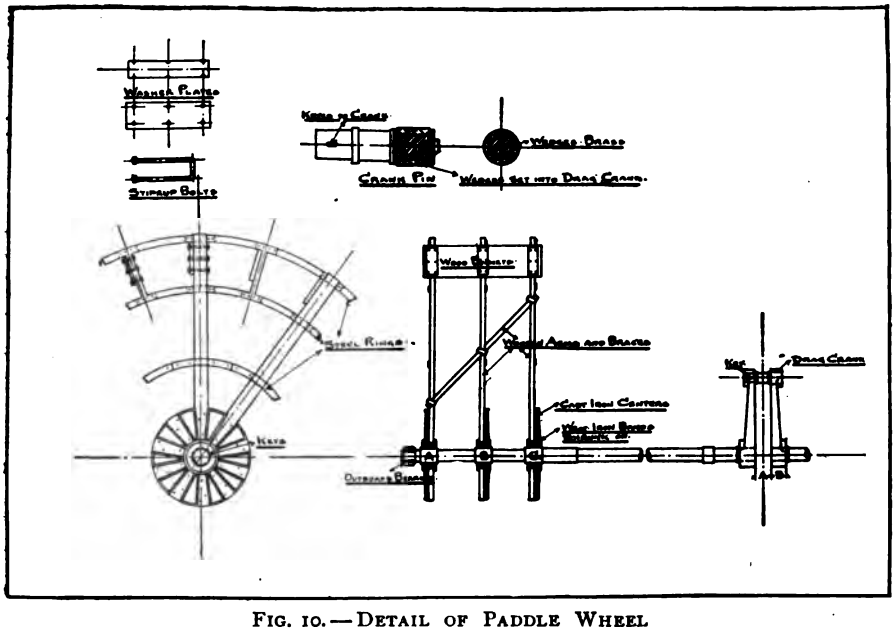

FIG. 10.—DETAIL OF PADDLE WHEEL

riveted to the two outer rings, each set of wooden and each set of iron arms carrying a float or bucket. About one-third of these buckets are made approximately 20 per cent. less in width than the others, the narrow buckets being placed nearest to the line of the dead centres, permitting the wheels to turn more easily at these points. The clearance between the ends of the buckets and the hull should be not less than 6 inches in any case.

The crank pin is driven hard into the driving crank and keyed. The other end of the pin is fitted with wedges into the "drag crank," as it is termed, the wedges being held in position by a disk and tap

bolt. Side-wheel steamers are generally constructed with light scantlings; the shafts are, therefore, subject to both bending and twisting strains. They should, therefore, be figured with a factor of safety of not less than ten. The cast-iron wheel centres are slipped on the shaft from the outboard end, C being larger in diameter than B, and B being larger in diameter than A. The centres are hung on tight-fitting keys, as shown in the end view. This wheel, as drawn, is what is termed a "radial wheel," with arms, diagonal braces, and buckets of wood, the rings and intermediate arms only being steel. It is very common practice nowadays to make the wheels of the feathering type and entirely of steel, including the buckets, which are then usually curved. The efficiency of the wheel is increased about 15 per cent. by so doing, provided that the wheel is properly designed.

I think it may be advisable at this point to go into the description of the valve gear a little more fully.

In beam engines the valve gear and mechanism for controlling the steam admission and exhaust are features of special interest. The arrangement of this gear was shown in Figure 6 and details in Figures 7 and 8. The steam cylinder, already shown in Figure 5, has diagonal wings cast on each side at the same angle as the gallows frame, to which they are well bolted. The top cylinder head is deep, with upper and lower webs, the stuffing box being formed in the cover and a brass neck bush being in the bottom. The top steam and exhaust passages connect with a cavity in the cylinder cover, there being a somewhat similar arrangement in the bottom cylinder head, the web of which is dished to a radius similar to that of the lower side of the piston. The cylinder is supported on the condenser, which also has inclined ribs, or wings, cast on the sides attaching to the gallows frame. In front of the cylinder, *i.e.*, on the engine room side, are two upright hollow cast-iron columns, or side pipes, as they are termed, having flaring tops. These are connected to the upper and lower steam and exhaust chests with a flat-plate expansion joint in each case at the top. There is a steam admission valve and an exhaust valve in each steam chest, a division plate separating them. The left-hand column, Figure 6, known as the steam chamber, connects the upper and lower steam chests, and the right-hand column connects the upper and lower exhaust chests. The lower exhaust chest connects directly with the condenser. The valves are of the double beat, poppet, or disk type, lifting vertically, the valve openings being shown clearly, although the valves are not shown in

place. Steam enters the upper steam chest from the boilers at X (Fig. 6) and down through the side pipe to the lower steam chest. As shown in Figure 5, there is a diaphragm cast in each chest dividing the steam from the exhaust; the exhaust from the top, therefore, passes down through the exhaust side pipe to the condenser.

The valve gear is essentially as follows. There are four eccentrics on the main shaft, two for steam, ahead and astern, and two for exhaust, ahead and astern. The eccentric rods operate the horizontal rock shafts, or valve shafts, Figure 6, on which are keyed four curved wipers. To the top of the stem of each valve is keyed a horizontal arm, the outer ends of which are attached to the vertical valve rods. On each valve rod is fixed a toe engaging with the wipers on the rock shaft. In front of the steam and exhaust chambers and below the rock shaft is the trip shaft for operating the valves by hand. This shaft has short wipers engaging with short toes on the valve rods. When this shaft is operated the upper steam and lower exhaust open together, and the lower steam and the upper exhaust likewise. The shaft is operated by a long starting bar inserted in holes in the shaft. Several large beam engines have been fitted with steam starting engines, giving ease and extreme rapidity in handling.

The stripper rods, as they are termed, which raise the ends of the hook rods clear of the rock shaft pins, are operated sometimes by hand and sometimes by foot, as shown here. By pressing the foot on this lever the stripper rods are raised, cutting off all connection between the hook rods and rock shaft. In ferryboats this is always done in making landings, the engine then being operated by the hand gear.

The lift of the valves should be carefully considered so that wire drawing may not occur. The amount of lift should be approximately one-fourth the diameter of the valve in each case, the area of the cylindrical surface due to the lift of the valve being equal to the area of the circle enclosed. Although the valves are always made self-closing, it has been found expedient to fit at least the steam valves with spiral steel springs so that they will act even more quickly, thus giving a rapid cut-off, and also so that the toes on the lifter rods will bear closely against the wipers, and so follow the movements of the latter. To the cylinder and to the two upright side pipes are attached three bracket bearings, which receive the rock shafts. These shafts are parted in the centre bearing, one shaft being operated by the steam eccentrics, the other shaft by the exhaust eccentrics. The outer end of each shaft has keyed

to it a crank arm in which is a slot, which permits vertical adjustment for the pin which engages with the ends of the hook rods, and hence changes the angular motion of the rock shafts. The hook rods connect the eccentric rods with the rock shafts. The eccentric rods being extremely long, it has been found advisable to truss them, which gives reasonable stiffness without extreme weight.

One of the most important problems to be considered in connection with the working parts of the beam engine is the proper sectional area of the connecting rod, and, in a lesser degree, the sectional area of the piston and air pump rods.

In the engine already considered, with cylinder 52 inches diameter and 12 feet stroke, fifty pounds maximum boiler pressure, and 28 inches vacuum, we found a load on the piston of approximately 136,000 pounds. As the fulcrum of the beam is in the centre of its length, we have an equal load on the connecting rod end of the beam. Lengths of beam engine connecting rods are made usually three times the length of stroke, which in this case would be 36 feet centre to centre. A connecting rod of this extreme proportion of length to diameter should be considered as a strut or column with rounded ends, the condition of fixed ends being too favorable. These rods are invariably stiffened by trusses extending the whole length, so that if the rod proper be allowed a factor of safety of 4, it is considered sufficient, the truss neutralizing most of the vibration and adding largely to its resistance to bending.

Under ordinary conditions, should this rod fail it will be by bending and not by direct crushing. A complete theory of this phenomenon is lacking, and the formula which has been here adopted is founded partly on theoretical and partly on empirical investigation. These investigations were made by Gordon. The values of the constants were also determined by Gordon. Where P is ultimate load, S sectional area in square inches, h diameter at centre of length of connecting rod in inches, l length of connecting rod in inches, a a constant determined by experiment for ultimate strength $= \frac{1}{8000}$ for wrought iron, f a constant for ultimate strength $= 36{,}000$ for wrought iron, the following equation gives the ultimate load.

$$P = \frac{fS}{1 + 4a\frac{l^2}{h^2}}.$$

S must be assumed and may be taken for trial as $\frac{\text{working load}}{2000}$ in the case of beam engines.

We found 136,000 pounds to be the working load.

Then $\frac{136000}{2000} = 68$ square inches sectional area of rod at centre $= S$. The diameter due to that area is approximately $9\frac{5}{16} = h$.

$$P = \frac{36000 \times 68}{1 + 4 \times \frac{1}{3000} \times \frac{186624}{86.7}} = 632558.5 \text{ pounds ultimate load.}$$

$$\frac{632558.5}{136000} = 4.6 \text{ factor of safety.}$$

This formula I have used for a number of years in arriving at suitable dimensions for long connecting rods, piston rods, etc., and have found it to be exceedingly reliable.

Finally it may be of interest to know something of the early speed performances of passenger steamers fitted with beam engines.

One of the earliest day boats on the Hudson River was the *Albany*, built in 1826. She was 212 feet long overall, 26 feet beam, and 9 feet depth of hold. The cylinder was 65 inches diameter by 10 feet stroke, boiler pressure forty pounds per square inch, the wheels being 24 feet diameter. In 1839 this vessel was lengthened and the beam increased to 28 feet. In the year 1840, after the alterations, she made the trip from New York to Albany in eight hours thirty-three minutes, giving an average speed of seventeen miles per hour. The most notable speed performance in this connection is that of the *Mary Powell*, still on duty and one of the most efficient vessels of the Hudson River fleet today. The vessel was built in the year 1861, being, therefore, forty-six years old. Her length is 294 feet overall by 34 feet 3 inches beam by 64 feet beam over the guards by 9 feet depth of hold, with a draught of 6 feet. Her cylinder is 72 inches diameter by 12 feet stroke. The wheels are 31 feet diameter, with twenty-six buckets 10 feet 6 inches long and 18 inches wide, the dip being 42 inches. She has two boilers which are placed on the guards. The boiler pressure is forty-five pounds per square inch. In the year 1874 she ran from New York to Poughkeepsie, a distance of seventy-five miles, in three hours and nineteen minutes, actual running time, and giving an average speed of almost twenty-three miles per hour exclusive of stops.

The following are some of the particulars of this vessel.

Length on water line	286 feet
Length overall	294 feet
Beam at water line	34 feet 3 inches
Beam at guards	64 feet
Depth of hold	9 feet
Mean draft	6 feet
Diameter of cylinder	72 inches
Stroke	12 feet
Cut-off	Half stroke
Average revolutions	22
Diameter of air pump	40 inches
Stroke of air pump	62 inches
Diameter of shaft	15 inches
Diameter of wheel extreme	31 feet
Length of buckets	10 feet 6 inches
Width of buckets	18 inches
Number of buckets on each wheel	26
Mean immersion of buckets	42 inches
Number of boilers	2
Diameter of shell of boilers	10 feet
Extreme length of boiler	26 feet
Total grate surface	152 square feet
Total heating surface	2,660 square feet
Steam pressure	45 pounds

ORE DEPOSITS OF THE EASTERN GOLD BELT OF NORTH CAROLINA[1]

By W. O. CROSBY

Introduction

The crystalline belt of the Atlantic Seaboard, south of New York, attains its maximum breadth of 220 miles on the northern border of North Carolina; and it is in this state that it is most widely characterized by the occurrence of gold in workable deposits. Half a dozen auriferous belts have been recognized by Nitze and Hanna.[2] These are, in the main, coincident in position and trend with the northeast-southwest zones of metamorphic slates and schists, which, more than any other feature, give character to the geological map of North Carolina. The central gold belts, accompanying the main zone of slates and associated igneous rocks, are much the more important and persistent, and may be regarded as continuous northward across Virginia and southward into South Carolina. The eastern belt, on the other hand, is the shortest and, economically, one of the least important. Its extreme length does not exceed twenty-five miles, the narrow band of slaty rocks to which it belongs passing, both to the northeast and the southwest, beneath the coastal plain formations. But, although limited in area and production, this belt is, perhaps, comparable with the central belts or any part of the seaboard crystallines in the variety of conditions under which the gold occurs. It lies chiefly in the northeastern part of Franklin County and the northwestern part of Nash County, on the watershed of Fishing Creek and other tributaries of Tar River. The elevation is, roughly, between 400 and 500 feet; and the Tertiary peneplain has here an exceptionally perfect development, the reliefs separating the slightly incised stream courses consisting of broad, flat-topped peneplain remnants, bounded by gentle lateral slopes.

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[1] Reprinted from the Transactions of the American Institute of Mining Engineers.

[2] North Carolina Geological Survey, Bulletin No. 3, p. 15.

General Geology

The eastern gold belt is separated from the central gold belts by the granitic rocks of the Raleigh, Louisburg, and Warrenton area; and these plutonic rocks are clearly younger than and intrusive in the associated metamorphic sediments. In traveling eastward from Louisburg or southeastward from Warrenton to the mining district, it is evident that we pass from a complex of granitic and gneissic rocks and various schists to an area of prevailing quartzites and siliceous slates, which are, however, freely intersected by the plutonics. Presumably, the sedimentary rocks are wholly of early Paleozoic age; and certainly their relations to the igneous rocks, so far as observed, are essentially identical throughout the district. The general line of strike of the sedimentary formations, as previously indicated, is northeast and southwest; and the prevailing dip is southeasterly at high angles. No effusive rocks, either acid or basic, have been observed in this district.

Almost universally, the rocks, of whatever kind, including even the hardest and most siliceous quartzite, are deeply rotted to normal saprolites; and both lithologic and structural features are thereby greatly obscured. Furthermore, the upland or peneplain surface is very generally overspread by a mantle of fine quartz sand. In part this sand appears to be simply the saprolite phase of the quartzite; but elsewhere it is horizontally stratified and includes, at least basally, layers of quartz gravel; and it seems then to require correlation with the Columbian formation.

Genetic and Structural Relations of the Gold-Bearing Formations

Sedimentary and Plutonic Rocks.—First in order of age come the sedimentary rocks, consisting chiefly of normal quartzite, grading through siliceous slates into metamorphic clay slates or phyllites. Intersecting these terranes in a highly irregular manner, and often transversely, is the complex of plutonic rocks, among which diorite, normal granite, and pegmatite are especially prominent.

The diorite is believed to be here, as in so many other plutonic regions, an earlier, peripheral, basic phase of the same body of magma which has yielded the granite; and it is clearly cut by dikelike masses of granite. Both the diorite and granite exhibit marked variations in texture and composition. They are frequently gneissic; and a sheared and chloritized part of the diorite is the chloritic schist of other writers.

The pegmatite, on the other hand, is clearly a later phase of the granitic magma, and forms irregular dikes in all the other rocks of the complex, both igneous and sedimentary. So far as noted, it is of highly acid composition, consisting chiefly of megacrystalline quartz, acid feldspars, and muscovite.

Veins.—In part the pegmatite is highly quartzose, and shows an unmistakable tendency to grade into quartz veins, which are the feature of the complex of most particular interest so far as the occurrence of gold is concerned. This tendency and the occasional occurrence of coarsely crystalline muscovite, identical with that of the pegmatite, in otherwise normal auriferous quartz veins leave no room to doubt the genetic relation of the pegmatite dikes to some, at least, of the quartz veins, or that the gradation is a fact.

Large areas of the complex of sedimentary and plutonic rocks are traversed by an irregular network of quartz veins, varying in width from a line to 50 feet or more, but mainly rather narrow, and individually highly variable in size and trend. They are, without exception, massive and glassy; and bands, combs, vugs, or other indications of crustification or of endogenous origin are conspicuous by their absence, as are also the selvage phenomena of normal fissure veins. The veins have not, as a rule, been worked below the oxidized zone, although this is shallow; but indications of sulphides below the water level are very meager and often wholly wanting. Aside from the oxidation of the scanty sulphides, the quartz veins have, in general, survived the rotting of the enclosing formations, and are now traceable, *in situ* and essentially intact, through the residuary detritus or saprolite.

In the central gold belts of North Carolina the writer long since recognized two essentially distinct types of auriferous veins: (1) Massive quartz veins of varying and often considerable size; devoid of definite selvage, combs, and vugs; relatively, and often absolutely, barren of sulphides; and the average gold tenor low to very low, but highly irregular or pockety, the gold being free, mainly coarse and nuggety, and thus especially favorable for the enrichment of placers. (2) Relatively narrow quartz-sulphide veins, with the normal structural features of true fissure veins; and relatively high and even gold values, the gold being rarely coarse and only to a limited extent free.

The veins of the first class are believed to be, in general, the older; to be, in part, approximately contemporaneous with the granitic rocks; and hence to have been formed under essentially plutonic conditions by

so-called magmatic waters and to admit of correlation, to some extent, as the end term of the pegmatites; while the veins of the second class are the product of the more normal circulaton of the ground water at less than plutonic depths, and represent the leaching of the upper and less metamorphic zones of the earth's crust by waters largely or chiefly of meteoric origin.

The veins of the second type form the basis, now and then, of continuously profitable mining operations; but those of the first type are rarely payable except locally and transiently, where a pocket or bonanza is encountered. These are the "specimen" veins, which are most profitable to man where they have been extensively mined by the slow processes of erosion and the product concentrated in placer deposits. Again, having been formed under approximately plutonic conditions, and not being in any large degree dependent upon sulphides for their values, the veins of the first type are not, to any important extent, subject to secondary enrichment by downward leaching. In other words, their marked variations of value are primary and do not, as in the sulphide veins, admit of close correlation with depth, both the coarseness of the gold and its uneven distribution being consonant with a quasi plutonic origin, which has allowed the principle of segregation to accomplish its most perfect work, bunching the gold in pockets within the veins, and in nuggets within the pockets.

Obviously, the veins of the eastern gold belt belong to the first or nonsulphide type; and in this fact we find the key to the history of gold mining in this district. Also, it may be noted here that the best values are found, as a rule, in the narrower veins, the wide ones being of little or no economic interest.

Impregnations.—The immediate country rock, be it granite, diorite, or quartzite, of the quartz veins and veinlets is often slightly impregnated with gold; but it is doubtful if the degree of impregnation is ever sufficient to make the undecomposed hard rock a practical ore. With the saprolite, however, the case is somewhat different, since it is easily mined and requires no crushing. The mineralized or impregnated granite saprolite, known locally as the "white belt," usually carries the best values. We are considering here a type of deposit—metasomatic impregnation and replacement—which elsewhere in the Southern Appalachian region has proved of exceptional importance, from a mining point of view. But in this eastern gold belt it is, even when reduced to the condition of saprolite, of little economic interest, the values being,

in general, still too low to justify metallurgical treatment, and the proportion of coarse gold too low to permit a large saving by placer methods. In comparison with the veins, the impregnations are noteworthy for the finely divided condition of the main part of the gold and for its relatively even distribution. As in the veins, however, sulphides are meager or wholly wanting. In brief, the impregnations partake of the character of the veins which they border, save that the gold is prevailingly fine instead of coarse, and hence unfavorable for the enrichment of placers.

Placers.—Long-continued and extensive erosion, resulting in the peneplanation of this region, set free a notable amount of the coarse gold of the quartz veins and effected its concentration in residuary placers adjacent to the outcrops of the veins from which it was derived. Subsequently, during the Columbian submergence, this residuary gold was still further concentrated, as a marine placer, in the basal layers of the Columbian gravels. Finally, during the erosion of the gravels and the trenching of the underlying peneplain by the modern valleys, the gold again became a residuary deposit; but in large part, also, it was carried down the slopes and experienced a further concentration in the gravels of the stream beds. Thus, for the surficial as for the bedrock formations we may recognize two principal types of auriferous deposits: (1) residuary and marine placers, representing a primary, vertical concentration in a plane, during the development of the peneplain; and (2) stream placers, representing a secondary, horizontal concentration in a line, during the trenching of the peneplain.

The bedrock deposits—veins and impregnations—are, as we have seen, of little economic interest, except locally for the saprolite phase; but where nature has mined these formations by cubic miles and concentrated the gold in the ratio of thousands into one, the results may be very interesting, although the deposits are quickly exhausted and do not afford a basis for long-lived mining.

Mining Notes

The writer's observations in the eastern gold belt were chiefly confined to three properties; but these appear to illustrate satisfactorily the normal range of conditions for the district.

Alston Mine.—This property is a part of the plantation of Edward Alston, in Warren County, about 16 miles southeast of Warrenton,

and on the northwestern margin of the gold belt. Gold was first discovered here in 1847 through the finding of a nugget in the road by one of Mr. Alston's servants. The situation is a low knoll of saprolite in which may be readily recognized, in order of age, quartzite (sometimes micaceous and garnetiferous), diorite (fine, dark, and chloritic), granite (fine, white, and micaceous), dikes of pegmatite, and a plexus of quartz veins. The superficial, residuary deposit or placer has been worked over an area of an acre or more, yielding a considerable amount of coarse gold. Several of the quartz veins have been prospected to the water level (25 to 30 feet). These have also yielded good values; but they are much too small to admit of profitable mining. The fine, impregnating gold is chiefly confined to the vicinity of the quartz veinlets in a band (dike) of granite saprolite 20 to 30 feet wide, forming the "white belt" of this property. In the pan, this impregnating gold appears as numerous very minute colors of remarkably uniform size, a condition highly characteristic of this type of deposit and making impossible any large recovery by placer methods.

Sturgess (Portis) Mine.—This mine, the best known and most productive of the eastern gold belt, is situated near Ransom's Bridge in the northeastern corner of Franklin County, at an elevation of about 100 feet above Shocco Creek. The extent of the workings and the variety of deposits which they exhibit make this property exceptionally favorable for the study of the geologic relations of gold in this district.

The predominant bedrock formation is the diorite, which is, at most points, thoroughly rotted, yielding, superficially, a deep red soil. Cutting through the diorite saprolite are occasional dikes of fine-grained granite saprolite (white belts). One of these is only 4 to 5 feet wide, while another is above 70 feet.

Both the diorite and granite are traversed by a network of very irregular quartz veins, of all sizes up to 2 feet thick. They are said to be generally auriferous, with pockets running thousands of dollars to the ton, the small veins being relatively the richest. The granite saprolite, or white belt, also carries appreciable, and, in part, workable values, although the minute subdivision of much of the gold prevents a high recovery.

As usual in the eastern gold belt, the surficial deposits have been most productive. These include: (1) a considerable area of Columbian gravel, the basal layer of which, resting unconformably upon the diorite and granite saprolites, contains workable values; (2) a still larger area

of residuary placer, where the Columbian gravel has been removed by erosion and the gold left directly upon the surface of the underlying saprolite; and (3) the stream gravels in the bed of a minor water course or "branch," the valley of which trenches the saprolite.

Thus we may recognize here, in obvious genetic relation, five available sources of gold: two original or bedrock sources—the quartz veins and the accompanying impregnations of the granite saprolite or white belt; and three secondary or placer sources, marine, residuary, and stream.

The Columbian gravel is still largely intact; but the residuary and stream deposits have been worked to the verge of exhaustion; and to these may be credited a large part of the total product. In part, also, the quartz veins and white belts have been worked to depths of 20 to 30 feet, the saprolite being washed and the quartz trammed to a twenty-stamp mill and crushed. The chief handicap to the operations has always been the lack of water, which can be had in quantity or under pressure only by pumping. Were a gravity supply available, hydraulicking of the entire property down to the "branch," followed by the milling of the quartz thus mined, and the subsequent cleaning up of the "branch" with a dredge would, doubtless, yield interesting results.

North Carolina Placer Mine.—The property of the North Carolina Dredging Company is on the same "branch" which traverses the Sturgess mine, and immediately below the latter. The valley floor is here several hundred feet wide, with a very low gradient; and the conditions are in every way favorable to the operation of a dredge. A low dam has sufficed to create the necessary pond for a Robinson chain-bucket dredge with a daily capacity of 1,000 cubic yards, working 14 feet deep. The pay streak is a layer of clean gravel 6 inches to 3 feet thick, on bedrock, with a layer of tough clay over it. Some gold is found in the silty overburden; but it is mainly in the gravel; and the values are fairly even across the valley, although greatest near the middle. The gold is mainly fine to very fine, or such as might have been transported by this feeble stream during a recent period of elevation, when it was flowing on bedrock.

THE BROADER FEATURES OF THE GEOLOGIC HISTORY OF NORTH AMERICA IN DIAGRAM

By HERVEY W. SHIMER

THE following article is an attempt to simplify and make easy for remembrance the main changes in the relative position of sea and land, and to indicate the general effect of this upon the climate, fauna, and sediment. The discussion of these changes and their corresponding effects is based largely upon views advanced by T. C. Chamberlin. The first part deals with a general discussion of these theories, while the second applies them by diagram to the North American continent.

The alternation of the subsidence of much of the land beneath the ocean with its reëmergence as a land surface is a familiar geologic fact. It is borne witness to by many unconformities between marine sediments, as well as by the alternation of thick and widespread deposits of limestone with strata of clastic origin—sandstone and shale. For example, the limestone formations of the Ordovician, middle Silurian, mid-Devonian to mid-Carboniferous, and lower Cretaceous are usually followed and preceded by clastic sediments or unconformities.

This alternation of subsidence with reëlevation was given a theoretic reason by Chamberlin in his discussion of the "Ulterior Basis of Time Divisions."[1]

He suggests that after the folding of portions of the earth's crust into mountains "in the process of periodic readjustment of the earth to its internal stresses," *i. e.*, shrinkage, "portions of the crust are thrust up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium by virtue of the slow fluency or quasi-fluency of the rocks." The settling back, which takes place very slowly, gradually permits the sea again to cover much of the land. This advance of the sea over the low-lying portions of the land is aided by the transference of material by rivers and waves from

[1] Journal of Geology, 1898, **6**, 450.

the land into the ocean, thus "displacing an equivalent amount of water and raising the sea level proportionately."

The clear and comparatively shallow waters of the broad seas enabled multitudes of lime-secreting organisms to thrive, and while their remains built up great beds of limestone, they at the same time added to the water, and naturally also to the air, great quantities of CO_2.[1] For when the organism, such as a coral polyp, takes the $CaCO_3$ from the water to build up its hard parts, it sets free the combining CO_2 which is necessary to hold it in solution, since in order to dissolve, for example, limestone and keep it in a soluble state as it is in sea water, some CO_2 in addition to the $CaCO_3$ of the rock is necessary, and hence when this is again returned to the rock condition, as it is in the coral, this extra CO_2 is set loose. As this deposition of limestone and consequent release of CO_2 is taking place in the broad epicontinental seas all over the world at the same time, there would result a notable increase in the carbon dioxide of the atmosphere. Carbon dioxide, in common with water vapor, possesses the peculiar property of being able to retain the sun's heat, but unlike the latter, it is active at any earth temperature. Thus, with an increase of this constituent in the earth's atmosphere, there would result an increase of heat, and with an increase of heat an increase of humidity; for where there is a stable higher temperature, more moisture can be held in suspension.

On the other hand, when the seas upon the continents are gradually withdrawn by the deepening of the ocean basins and by mountain folding, the release of CO_2 would be replaced by its consumption, since in the wearing down of the land areas CO_2 is necessary in getting much of the material into a transportable, *i. e.*, soluble, form. It is consumed in the decay of crystalline as well as of sedimentary rocks. Hence during times of enlarged and higher continents there would be a decrease in the carbon dioxide of the air and a consequent lowering of the temperature, with a *pari passu* drying of the atmosphere. At such times the broad, shallow seas would be withdrawn from the land, and the continental shelves be reduced to very narrow zones, over practically all of which clastic sediments would be deposited. In such waters many of the lime-secreting organisms, such as corals, could not live. There would thus be formed during this period no limestone beds, except in a few local areas, but instead, great thicknesses of sandstone, shale, etc. This would be

[1] T. C. Chamberlin: "The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere," Journal of Geology, 6, 609.

deposited around the margins of the continents, as well as upon the continents themselves—the latter through the agency of overflowing (aggrading) rivers and also in enclosed basins. With these there would be deposits of salt and gypsum, owing to the low humidity. The color of much of the sediment would be red, since in being deposited upon the land where little water was present to cause leaching, the iron of the original rocks would remain in the sediment and would be changed through oxidation to the red ferric state. At the same time, the higher mountains would cause greater local precipitation; and if the temperature of one of the places of greater winter precipitation were sufficient to cause the falling moisture to take the form of snow, more might fall during winter than could be melted during summer, and thus glaciers would form.

There would thus in the earth's history be alternating periods. During periods of continental depression great deposits of limestone would form most of the sedimentary rocks, for even along the margins of the land, clastic deposits would be much less abundant than at times when the land stood higher. At the latter part of such periods when long continued without continental elevation, erosion would have reduced most of the land to a state of peneplanation, and thus the deposition of clastic sediment would be reduced to a minimum. The temperature and humidity would be high. Individuals of marine life would be exceedingly abundant, and this fauna would be more or less similar all over the world, *i. e.*, cosmopolitan (as in Ordovician, mid-Silurian, Carboniferous, etc.), owing to the presence of broad continental shelves and the absence of many land barriers, thus favoring free migration.

On the other hand, during the sea's withdrawal and the accentuated height of the land due to mountain folding, very little limestone would be deposited, but instead, widespread and thick beds of sandstone and shale. Much of this sediment would be red, as, for example, that of the Permian and Triassic. The temperature and humidity would be low, causing deposits of gypsum and salt, such as those of the upper Silurian, the Permian to the Trias, and the Quaternary to recent. Likewise, at times, the presence of glaciers would be favored during periods of most marked land elevation, as in the Permian and Quaternary. Marine life would be excessively decreased in abundance, this result necessarily following upon the narrowing of the shallow water tracts where most marine forms live, *i. e.*, the continental shelves and other epicontinental seas. The faunas that persisted would soon become provincial in char-

acter, since the narrow continental shelves and the broad land areas would prevent free migration. The land life, on the other hand, would find this its time of free migration, as is seen in the wide occurrence of similar land animals during the Permian to the Trias, the Tertiary to the Quaternary; and as is evidenced likewise in the wide introduction of modern land plants between the lower and upper Cretaceous, as noted in the Morrison and Dakota formations, and in the striking similarity of the Permian plants of South America, South Africa, Australia, and India.

The above discussion in its relation to the broader geologic history of North America[1] may be represented by the following diagram.[2]

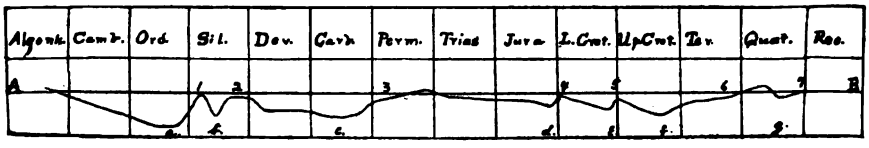

DIAGRAM TO REPRESENT THE PRINCIPAL OSCILLATIONS OF THE NORTH AMERICAN CONTINENT

The letters (*a*, *b*, etc.) indicate times of submergence of much of the continent; the figures, times of elevation or enlargement. The curves are drawn with reference to the present size of the continent, which is represented by the line *AB*.

The line *AB* represents the present height of the continent. The position of the curves was determined by letting the present land surface of the continent be represented by 1, and comparing this with the land surface during the preceding geologic eras as shown by the spread of marine sediment. This data is based largely upon the geologic maps of "Chamberlin and Salisbury's Geology," Volumes 2 and 3.

The lower portions of the curves (*a*, *b*, *c*, etc.) thus indicate times when much of the North American continent was covered with comparatively shallow seas, in which were laid down the widespread and thick deposits of limestone. The marine faunas of such periods were very abundant and quite similar in widely separated regions, making easy the correlation of the strata of these ages. For example, the Ordovician of Australia and eastern North America are very similar.

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[1] For the sake of simplicity only the broader elevations and depressions, affecting largely most of North America, are noted here.

[2] I am indebted to Mr. A. O. Christensen, Massachusetts Institute of Technology, 1907, for some suggestions of this diagram.

The upper portions of the curves indicate times of elevation of the continent; those parts that go above the line *AB* are necessarily doubtful, as it is at present impossible to say how much larger than its present size the continent ever became. These upper curves (1, 2, etc.) represent either an absence of all sediments or the presence of clastic sediments, these latter deposited either upon the land or along its borders. Either while the land is being elevated or, more usually, while it is being again depressed, the clastic sediment is laid down at the sea margins, and by the progressive advance of the seas upon the land this sediment gradually becomes deposited upon much of the land area. These upper portions of the curves also indicate the more arid and colder times, and hence here occur the most important deposits of salt and gypsum. At such times, likewise, the marine faunas are most decreased in numbers and most provincial, thus making it difficult to correlate the strata of different regions. The upward swings of the line mark the times of the geologic revolutions closing the limestone epoch and inaugurating the clastic. Thus 1 represents the time of the Taconic revolution; 3, the Appalachian; 4, the Sierra Nevada; and 6, the Rocky Mountain or Laramide. At 2, 5, and 7 the withdrawal of the seas does not seem to have been accompanied by any great mountain folding.

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CONTRIBUTION FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE PREVENTION OF STREAM POLLUTION BY STRAWBOARD WASTE[1]

BY EARLE BERNARD PHELPS

INTRODUCTION

THE disposal of the waste liquors resulting from the manufacture of strawboard forms one of the most important problems connected with the prevention of stream pollution. In 1900 the total production of strawboard in the United States was 157,534 tons at 59 factories. For each ton of strawboard manufactured there were discharged into the streams about 65,000 gallons of waste liquor that contained 1,173 pounds of straw and mineral matter and 490 pounds of lime. The total waste discharged into the streams in 1900 amounted to 10,239,710,000 gallons of liquor, containing 184,777,382 pounds of straw and mineral matter and 77,191,660 pounds of lime. This enormous waste was discharged by 59 plants of various sizes, but as most of these mills are along small streams the resulting pollution is very apparent. Some idea of the amount of this pollution may be obtained from Plate I, *B*. The baled straw shown is a three months' supply for a mill having an output of 30 tons a day. In three months one-third of this straw will be discharged into the stream as waste matter.

The problem of the disposal of the waste water has been studied by Professor R. L. Sackett, of Earlham College,[2] and the present investigation is a continuation of the work of Sackett along new lines. In approaching the problem it is necessary to keep constantly in mind the economic conditions affecting the industry. The low selling price of the

[1] Reprinted by permission from Water-Supply and Irrigation Paper, No. 189, United States Geological Survey.

[2] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 9–35.

PLATE I

A. VIEW OF STRAWBOARD MILL

B. PILES OF BALED STRAW
One-third, by weight, will be wasted in three months

product, the immense volume of waste water necessary, and the fact that competition between strawboard and other forms of cheap board is active, make it quite impracticable for the manufacturers to adopt any process involving serious expenditures. The solution of the problem must be sought in a process which will show an actual saving. Aside from the matter of the recovery of by-products of commercial value, this means that the process must compete in cost with the present unsatisfactory sedimentation methods employed at many of the mills, to the cost of which may reasonably be added the almost constant expense of lawsuits and injunction proceedings, the latter in some cases causing the closing of the mill.

As a result of this study it has been found that sedimentation of the waste water for a short period, followed by filtration thru sand at high rates—the so-called mechanical filtration, but without coagulants—will produce an effluent from which more than 90 per cent. of the suspended organic matter has been removed. This effluent, while not ideal, is probably purified to such an extent that, allowing a factor of safety of 2 for impurities in the stream, it may be discharged into streams having a minimum flow of twice the discharge of the mill without producing a nuisance. The cost of filtration by this process, after the initial cost of installation, is practically reduced to the cost of pumping the wash water. The final result is a heavy sludge, whose volume is less than 5 per cent. of the initial volume of the waste. Ultimate disposal of this sludge could be made either by discharge over land for spontaneous evaporation, by evaporation by means of artificial heat, or by filter pressing. The sludge has some value as a fertilizer, and there are also certain commercial uses to which it seems to be adapted.

THE MANUFACTURE OF STRAWBOARD

The following description of the manufacture of strawboard is taken from Professor Sackett's paper:[1]

Steaming in Rotaries

"The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a 'rotary' . . . is filled

[1] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 13–15.

with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. . . . This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark yellow, pulpy mass. This 'stock,' as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the *Journal of the Society of Chemical Industry*[2] says:

"'The chemical action of the milk of lime on the incrusting materials surrounding the straw fiber is not a vigorous one. These incrusting materials are not completely, nor, indeed, to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water.'

"The yield of pulp at this point will be from 75 to 80 per cent. of the weight of the original material. . . .

"The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent. of water and from 6 to 7 per cent. of lime. This is equivalent to from 12 to 14 per cent. of lime in the dry straw. Since the original charge of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent. lime, practically none of the latter has drained out with the condensed steam. This drainage from the stock piles forms but a small part of the waste sewage. It is straw colored and very turbid, carrying a small quantity of fiber broken fine in the rotaries.

Washing

"This process is much more drastic, and it is here that the great volume of waste is produced.

[2] For February 28, 1894, p. 101.

"The stock is run thru washing machines for the purpose of removing the lime. . . . The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, thru which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times thru the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. . . .

Drying

"After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats, where it is mixt with large quantities of water and past over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are prest down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in thru hollow bearings. As the pulp passes on thru the train it is constantly prest and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent. of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish."

THE DISPOSAL OF WASTE LIQUOR

Method in Use

At present, so far as can be learned, the only method of treating the waste liquor in actual use by the manufacturers is that of prolonged sedimentation in open fields. The overflow water from these fields is not satisfactorily clarified at all times of the year. During cold weather it is fairly clear and can be discharged without serious harm. During the summer, however, a very offensive fermentation takes place in the accumulated sludge, giving rise to objectionable odors and blackening the water. At such times the aim is to hold all the waste water in the ponds, trusting to evaporation and to the storage capacity of the ponds until cold weather again relieves the situation and the increased flow of the stream permits a discharge of the surplus water stored. The most serious objection to this process, which seems to be satisfactory to riparian owners below, is the fact that these ponds are continually filling up with a soft mud, which destroys their function as sedimentation basins and renders them useless for other purposes. The time must come, even in the most favorable situation, when additional land cannot be afforded for this purpose. A second objection is that the accumulated sludge is held for years and slowly putrefies. The organic matter of the waste is but slightly nitrogenous and is fairly stable. It probably contains some reducing sugars capable of rapid fermentation if kept in concentrated form and if given at the same time some nitrogenous matter. The slow decomposition of the stable straw material supplies the necessary nitrogen, and the result is a very rapid multiplication of the putrefactive organisms and an accompanying offensive putrefaction. Laboratory experiments have shown that the soluble sugars by themselves, as found in a filtered sample of the waste water, do not ferment or decompose, and that even the unfiltered waste is not subject to a quick putrefaction such as characterizes sewage matter. In fact, bottles have been stored for over a year without any evidence of fermentation, and it may very reasonably be held that the necessary nitrogen comes largely from the bottom of the ponds, rather than from the sludge itself. Inspection of the stream below one of these ponds showed that, while putrefaction was barely noticeable and not at all offensive in the pond itself, the admixture of some of this water with that of a small brook, highly polluted with the refuse of a slaughterhouse, had immediately a very offensive result. Investigation of the condition of the streams below

these mills reveals the fact that the most serious nuisance generally occurs at a point very remote from the mill itself. It is directly caused by the slow decomposition of material deposited in the bed of the stream. The conditions are doubtless aggravated by the simultaneous precipitation of other polluting substances, notably sewage, brought about by the free lime of the strawboard waste.

The effective solution of the problem lies in the rapid separation of the solid matter from the dissolved sugars and lime and a subsequent dilution of the latter so that they shall be innocuous. The insoluble material when dry is entirely stable. The present system, therefore, is not only unsatisfactory from the economic side, but it works on a wrong principle for satisfactory purification in that it encourages putrefaction.

The cost of these ponds at four of the larger mills of the United Box-board and Paper Company, as stated by an official of that company, has been, in round numbers, to date, $10,000, $15,000, $18,000, and $8,000. In the last case the results were still unsatisfactory, and after a considerable expenditure on other experiments the company has been obliged to close this mill.

Proposed Methods

Centrifugal Separation

Centrifugal separation of the solid matter from the liquor was tried at Tiffin, Ohio, in 1904. It has not been possible to obtain more definite information concerning those experiments than is contained in the trade papers of that time. It is understood, however, that the results were quite satisfactory, but that the cost of operation was prohibitive. The account referred to (see *Paper Trade Journal,* February 2, 1905) states that the effluent was clear and colorless and that the residue was found by analysis to be valuable as a fertilizer.

Precipitation with Carbon Dioxide

As a result of his investigations Sackett concluded that plain sedimentation would remove about 10 per cent. of the suspended solids in twenty-four hours, and that during the ensuing twenty-four hours the additional removal was very slight; that good purification could be effected by chemical precipitation only by using sulfate of aluminum in excessive amounts and at an entirely prohibitive cost; that sulfate of iron gave inferior and unsatisfactory results; and, finally, that by a

process of precipitation with carbon dioxide and lime an average removal of 85 per cent. of the suspended matter could be effected.

The process recommended by Sackett consists in (*a*) saturation of the waste water with carbon dioxide to form bicarbonate with all the lime present; (*b*) addition of lime equal to that already present to form a normal carbonate; (*c*) sedimentation of the precipitated carbonate and consequent dragging down of some of the organic matter; and (*d*) filtration of the resulting clarified liquor thru sand at rates of 500,000 to 2,000,000 gallons per acre per day. This process has never been used by manufacturers so far as the writer is aware.

It does not appear from Sackett's report that he tried the simpler but equivalent process of saturating one-half the total volume with carbon dioxide and then mixing with the other half. Such treatment would doubtless have precipitated the calcium fully as well, with a saving of one-half the carbon dioxide and all the lime required by the process recommended. An examination of the analytical data shows that the removal of suspended organic matter accomplished by the precipitation and sedimentation processes varied from zero to 75 per cent., with a mean value of 37 per cent. Experiments on plain sedimentation, made by the writer both in the laboratory and on a large scale in the field, show it to be equally efficient for the removal of suspended organic matter. The fact is that the precipitated carbonate of calcium is very finely divided and has no value as a coagulant. The process is valuable to remove the lime, if that be desirable. It hardly seems, however, that the value of discharging a lime-free effluent into the hard waters of the Middle West is at all commensurate with the cost of treatment.

LABORATORY INVESTIGATIONS

Chemical Study of the Soluble Matter

Several barrels of the strawboard waste liquor were shipped to Boston from one of the mills of the United Box-board and Paper Company, and on this material a series of investigations was carried out. Sackett's experiments with various coagulants were repeated and his results confirmed. It was found that the poor results obtained with any but excessive amounts of iron or aluminum sulfate were due to the presence of a substance in solution which forms soluble combinations with those metals. This substance was isolated by precipitation with hydrochloric

acid, and after repeated purification was found to have the following properties: It is an organic acid, probably related to the humic or ulmic acids of the soil and peaty waters. It exists in the waste water as a calcium salt, having partially neutralized the free lime used in the digestion. It is precipitated by strong acids, coming out as a dark-red substance which turns brown on slow oxidation in the air. It can be redissolved in a solution of sodium carbonate, giving a garnet-red solution. It dissolves in alcohol, giving a deep-red color, but oxidizes to a brown, insoluble substance. Its calcium and aluminum salts are not soluble when prepared from the insoluble acid, but the acid cannot be precipitated from its solutions by these metals. It appears that there are formed colloidal suspensions of the calcium and aluminum salts. The solutions have a bright yellow color and colloidal appearance. The iron compound is similar but of a green color. The sodium salt appears to be soluble and to dissociate into deeply colored acid ions.

A second substance isolated from the waste has the following properties: It is soluble in water and not precipitated by any of the common precipitants, including alum, ferrous sulfate, lead acetate (normal or basic), carbonates, hydrates, or acids. It is responsible for a large part of the color of the water and cannot be removed by any practical method.

These two substances with the lime make up the greater part of the dissolved material. They are entirely stable and do not undergo putrefactive change when stored in the incubator, either alone or mixt with varying proportions of tap water. In addition to these substances small amounts of reducible sugars are present. The amount is so small that in any material dilution of the liquor the dilution of these sugars will prevent their manifesting themselves as putrefactive agents. These sugars are probably responsible for the slow fermentation in the sedimentation fields after the lime has been sufficiently removed to allow the action to proceed.

Precipitation Experiments

Substances in suspension may be removed by filtration or by sedimentation. When the material is finely divided or of low specific gravity, either process may sometimes be assisted by the application of suitable coagulants. These tend to clot the small particles into larger flakes, and by their own greater density carry the clotted material to the

bottom. Two chemical substances are required, as a rule, to produce the necessary precipitation, one of which is generally the calcium bicarbonate found normally in the water. This calcium salt reacts with the sulfates of certain metals, notably iron or aluminum, to produce the sulfate of calcium and the hydrates of the corresponding metals. In the present case there is a large amount of free lime in solution. It would seem, therefore, that precipitation might be brought about by the addition of either copperas or alum. Experiments showed that copperas failed to react at all and that fair results could be obtained with alum, but only at a prohibitive cost. As will be seen in the accompanying tables of results, the removal of organic matter by alum was much better than that obtained by plain sedimentation.

RESULTS OF PRECIPITATION EXPERIMENT ON STRAWBOARD WASTE

Sample.	Suspended Solids.	
	Present.	Removed.
	Parts per million.	Per cent.
Raw waste	1,350	. .
Waste after two hours' sedimentation:		
With coagulant*	120	91
Without coagulant	560	59

* The coagulant used was alum in the proportion of 10 grains of sulfate of aluminum per gallon.

Increasing the amount of aluminum sulfate gave practically the same result. Smaller amounts gave indefinite and at times negative results. The use of 10 grains per gallon of sulfate of aluminum at 1 cent a pound would represent a cost of about 43 cents per ton of finished product of the mill. The studies on the nature of the dissolved material already referred to explain these poor precipitation results with alum. Soluble compounds are formed with the organic acid, instead of aluminum hydrate, the desired coagulant.

Experiments were made with carbon dioxide according to Sackett's procedure, and his results were confirmed. There was but a slight removal of suspended organic matter—about 30 per cent.—which could be produced equally well by plain sedimentation. In fact, under actual working conditions sedimentation was found to be even more effective.

Sedimentation Experiments

In a study of plain sedimentation it is important to know the rate of sedimentation and how this varies with the time. With satisfactory data on this point it is possible to estimate the amount of clarification which may be expected to result from any given period of sedimentation, and to establish the most suitable period for the case in hand. It was observed early in this work that apparently a large portion of the suspended solids settled out in a very short time, and that to all appearances further improvement was extremely slow. The determinations of the total solids given in the following table show that there is no practical advantage in sedimentation for a period of much over one hour.

Effect of Sedimentation on Strawboard Waste

	Suspended Solids.	
	Present.	Removed.
	Parts per million.	Per cent.
Liquor at beginning of experiment	1,344	. .
Supernatant after one hour	548	59
Supernatant after twelve hours	494	63

Summary

As a summary of the laboratory investigations, it may be said that the removal of the dissolved coloring and other organic matter and the lime in an economical way is impractical; that by plain sedimentation a removal of suspended material practically as good as the best removal observed with the use of a coagulant can be accomplished; and that a sedimentation period of one hour is sufficient for the removal of about 60 per cent. of the suspended solids, a longer period increasing this removal but slightly. For the removal of the remainder of the suspended matter there remains but one process—filtration. It was therefore decided to make an actual field test of this method of purification. The very large amounts of suspended matter to be handled seemed to eliminate at the outset the possible use of slow sand filtration, so that it was obvious that mechanical filtration at high rates and with some provision for removing the accumulated sludge from the surface of the filters was the only system applicable to the problem.

FIELD INVESTIGATIONS

Acknowledgments

In March and April, 1905, a visit was made to one of the mills of the United Box-board and Paper Company, at Urbana, Ohio. Every opportunity was given the writer to make a thoro study of the processes of manufacture, and it is here desired to make suitable acknowledgments to Mr. Rush E. Evans, division manager, and to Mr. D. C. Amerine, superintendent, for the many courtesies extended, both on that occasion and during the subsequent visit for the installation of an experimental plant.

Amount of Water Used

It was found that conditions were favorable for measuring the entire volume of waste water, as it left the mill in a waste flume. As a check on these measurements, observations of the rate of operation of the pump were made, all the water used being pumped from a large well under the mill.

A rectangular flume, whose mean width was 1.96 feet, was used for these measurements. A distance of 100 feet was measured off in a portion where the slope was practically constant. To determine the velocity of flow at various elevations in the flume, a float was used which was nearly as long as the width of the flume and was provided with vanes underneath, so that it always floated squarely across the flume. The following observations are the mean of a large number made at various elevations of water in the flume.

Mean Depth, Velocity, and Flow of Waste Water in Flume of Mill of United Box-board and Paper Company, Urbana, Ohio

Depth of water.	Velocity of flow.	Area of cross-section.	Flow.
Foot.	Feet per second.	Square foot.	Cubic feet per second.
.19	3.1	.37	1.1
.25	3.8	.49	1.9
.29	4.0	.57	2.3
.31	4.2	.61	2.6
.33	4.3	.65	2.8
.37	4.5	.72	3.2

These values of the depth and the corresponding flow were then plotted. The most probable line was drawn thru them, and that curve was used as the true rating curve of the flume in the subsequent calculations.

During the two hours from 10.45 A.M. to 12.45 P.M., March 30, a test run was made to determine the total flow. The following readings of the elevation of the water in the waste flume were made, and from these readings has been calculated the total flow for the two hours.

FLOW OF WASTE WATER IN FLUME OF MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO, MARCH 30, 1905

Time.	Depth.	Flow.	Flow for Fifteen-Minute Period.	
			Mean rate of flow.	Total flow.
	Foot.	Cubic feet per second.	Cubic feet per second.	Cubic feet.
10.45 A.M.	.29	2.3	. .	. .
11.00 A.M.	.29	2.3	2.3	2,100
11.15 A.M.	.33	2.8	2.6	2,300
11.30 A.M.	.33	2.8	2.8	2,500
11.45 A.M.	.33	2.8	2.8	2,500
12.00 M.	.33	2.8	2.8	2,500
12.15 P.M.	.38	3.4	3.1	2,800
12.30 P.M.	.36	3.1	3.2	3,000
12.45 P.M.	.33	2.8	3.0	2,700
Total	. .	. .	. .	20,400

This total flow of 20,400 cubic feet in two hours represents an average flow of 2.69 cubic feet per second.

A few measurements were made of the water running in the waste flume when the beaters were not running and again when the paper machine was stopt. The flow from the machine was found to be fairly constant at 1.4 cubic feet per second, and the beaters were found to discharge amounts of 1.2 to 1.8 cubic feet per second, depending on the number of beaters in operation at the time.

During the test run observations of the rate of operation of the

pump were made at short intervals. The pump was a double-acting duplex Smith-Vaile pump, with water cylinders 14 inches in diameter and with a stroke of 15 inches. Slip being neglected, the capacity of the pump is, therefore, 1.335 cubic feet per stroke, or 5.340 cubic feet per complete revolution. Following are the observations made on the pump and the calculated rate of pumping:

DISCHARGE OF PUMP AT MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO, MARCH 30, 1905

Time.	Revolutions per minute,	Discharge.	Time between observations.	Discharge of Pump between Observations.	
				Mean.	Total.
		Cubic feet per second.	Seconds.	Cubic feet per second.	Cubic feet.
10.45 A.M.	31	2.28	. .	. .	. .
11.00 A.M.	30	2.67	900	2.43	2,457
11.15 A.M.	30	2.67	900	2.67	2,403
11.30 A.M.	30	2.67	900	2.67	2,403
11.45 A.M.	30	2.67	900	2.67	2,403
11.55 A.M.	30	2.67	600	2.67	1,602
11.55 A.M.	40*	3.58	. .	. .	. .
12.25 P.M.	40	3.58	1,800	3.58	6,444
12.45 P.M.	38	3.57	1,200	3.48	4,176
Total pumped	. .	. .	. .	. .	21,888

* Changed.

During the test four of the seven rotaries were filled. Two hundred and fifty cubic feet of water are required for each rotary, or 1,750 cubic feet for the seven. Since all seven are filled only once in twenty-four hours, the water used in this process amounts to 73 cubic feet per hour for the whole day. The water so used during the two hours of the test was, however, 750 cubic feet, an excess of 604 cubic feet over the normal mean consumption. The amount pumped must, therefore, be corrected by this amount. The elevation of the water in the supply tank was 1 foot greater at the end of the test than at the start. The diameter of the tank is 12 feet. This storage amounts, therefore, to 113 cubic feet, and must also be applied as a correction. A small stream

of water was being wasted from the engine condenser. This stream was roughly estimated by float measurements to be about 0.3 cubic foot per second, or 2,160 cubic feet during the two hours of the run. These three corrections amount to 2,888 cubic feet, which is to be subtracted from the total pumped, 21,888 cubic feet, leaving a net pumpage of 19,000 cubic feet for two hours, or 2.64 cubic feet per second, a result in close agreement with the 2.69 cubic feet per second measured in the waste flume.

Raw Material and Finished Product

During this test run, careful weighings were made of the amount of finished board produced. The figures were as follows:

Product of Mill of United Box-board and Paper Company, Urbana, Ohio, for Two Hours, March 30, 1905

	Pounds
Gross product	4,841
Waste and trimmings	196
Net product	4,645

Dividing the total amount of waste liquor, 20,400 cubic feet, by the amount of net product gives 8,780 cubic feet, or, roughly, 65,000 gallons per ton of product. As the daily product of this mill is about 30 tons, about 1,900,000 gallons of waste water are discharged each day.

The charge of one rotary was carefully weighed. There were used 133 bales of straw, of an average weight of 102 pounds, or a total of 13,600 pounds of straw. The amount of lime was weighed, but the weight was somewhat in excess of the average amount used, as determined by the total weekly consumption of lime. The latter figure, which is 2,100 pounds per charge, will therefore be used. The total amount of straw used in the 7 rotaries is accordingly 95,200 pounds per day, and of lime, 14,700 pounds per day. Subtracting from this the 60,000 pounds of finished product leaves a waste of 35,200 pounds of vegetable and mineral matter from the straw and 14,700 pounds of lime, which is carried off each day in the 1.9 million gallons of water. Calculated into parts per million, these figures give about 2,400 parts of straw material and about 1,000 parts of lime. Analyses of average samples of the waste water gave about 600 parts of calcium or 840 parts of lime per million. The difference is due partly to the loss of lime during the draining of the digested pulp and largely to impurity of the lime.

Character of the Machine Water

Determinations of the lime were made on the well water and on the various waste waters. It was found that the greater part of the lime is washt out in the beaters, and that the water from the machine contained but little lime in excess of that in the raw water. The actual figures were:

Calcium in Waste Water

	(Parts per million)
Well water	238
Beater water	1,164
Machine water	380

A rough determination of the impurities was made by precipitating the lime and organic matter, with a large excess of alum. A 6-inch column of the beater water gave a layer of precipitate an inch thick, while the amount obtained from the machine water was too small to be measured.

Mechanical Filtration

In May, 1906, a small experimental filter was installed at this mill, in order to obtain some practical data on the efficiency of treating the waste by mechanical filtration. The filter and accessories were loaned by the New York Continental Jewell Filtration Company, of New York, thru the courtesy of Mr. R. E. Milligan, assistant general manager, and the expenses of shipment and installation were borne by the paper company.

Description of the Filter

The filter used is shown in Figure 1. The waste water, after passing the regulating butterfly valve, divided into two streams and entered the bottoms of the two sedimentation tanks. These tanks were of cypress, each having a diameter of 4 feet and a depth to the overflow line of 3.2 feet. The capacity of the two was 603 gallons. The water was delivered to the tanks thru half-inch holes in the sides of risers extending to the surface. The vertical distribution was, therefore, very uniform. Vertical baffles caused the water to flow completely thru the tanks, and a funnel-shaped overflow collected the clarified water from the surface of each tank and delivered it to the surface of the filter. The filter proper was of galvanized iron, set upon a cast-iron base, provided with a false bottom of fine brass screening. The diameter of the filter was 20 inches, and its total depth to the false bottom was 5 feet. Suitable

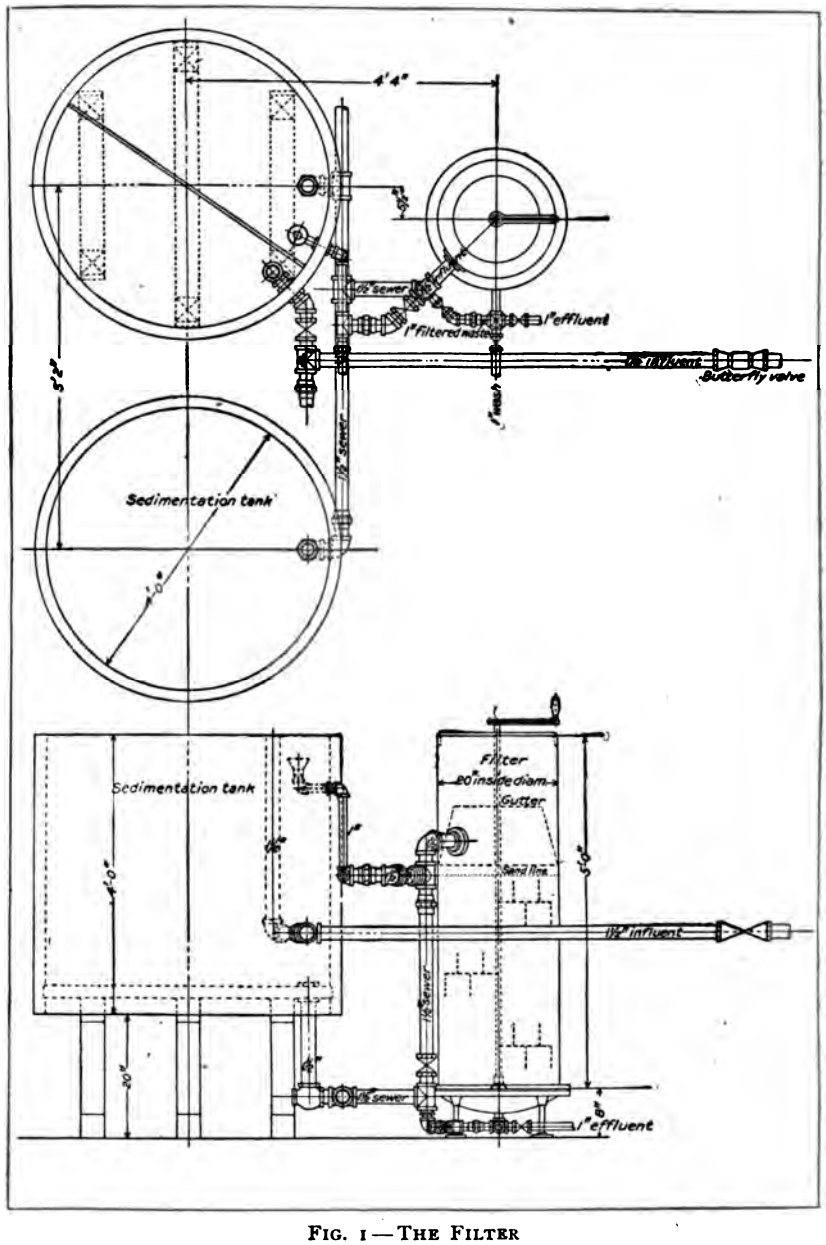

FIG. 1 — THE FILTER

connections and valves were provided, as shown in the drawing, so that the influent and the effluent water could be cut off, a stream of wash water could be admitted from the bottom, and the dirty wash water,

overflowing from the top, could either be wasted thru the sewer connection or returned to the sedimentation tanks. The device for stirring the sand during washing was operated by hand. Wash water was supplied from an elevated tank under such a head that a maximum flow of 25 gallons per minute, or 12 gallons per square foot per minute, was possible. A flow of about 8 gallons per square foot per minute was generally used. Suitable connections were also made between the bottoms of the sedimentation tanks and the sewer. A 50-gallon barrel at the end of the sewer line served as a measuring tank for the wash water

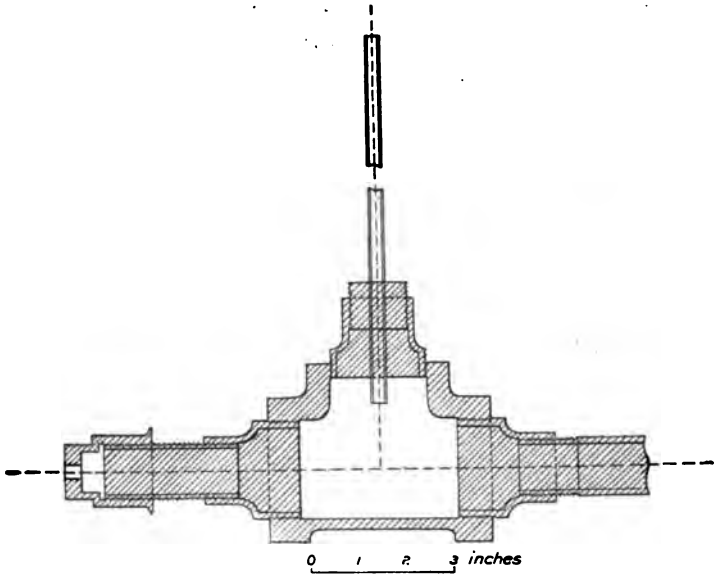

FIG. 2

or the sludge. The rate of flow thru the filter was regulated at the outlet by a standard orifice, a sectional view of which is shown in Figure 2. The orifice itself was a trifle over seven-sixteenths of an inch in diameter. The brass cap containing the orifice was screwed over a nipple of 1-inch pipe, which was in turn connected with a 2-inch tee. The opposite side of this tee was connected by a short pipe to the valve regulating the outflow, and a glass tube, fitted to the upper opening of the tee, permitted the static head on the orifice to be read at any time. The large sectional area of the tee as compared with that of the orifice reduced the velocity of approach to a negligible value. This device was roughly calibrated in the field and was subsequently carefully cali-

brated by discharging into a large measuring tank. The rough field values were found to be substantially correct.

The rate of inflow to the tanks was adjusted to the rate of filtration by the butterfly valve, actuated by a float in one of the tanks (not shown). The filter was filled to a depth of 3 feet with clean 16–30 beach sand, *i.e.*, sand which will all pass a screen with 16 meshes to the linear inch and be retained on a screen with 30 meshes. The water line was 18 inches above the surface of the sand.

The appearance of the filter and sedimentation tanks as they were set up is well shown in Plate II. Plate II, *A*, shows the sedimentation tanks, the influent pipe and controlling valves, and the lever arm of the float operating the butterfly valve. Plate II, *B*, shows the filter itself, the loss-of-head gage, and the connections with the tanks and the sewer. To the extreme right is the measuring tank, and passing between the two tanks on the ground the wash-water pipe line can be seen. The outlet of the filter is hidden from view behind the mound of earth in the foreground.

Preliminary Sedimentation

A number of tests were first made to determine the rate of change in the loss of head during filtration with varying periods of preliminary sedimentation. A uniform rate of filtration of 3.25 gallons per minute, equivalent to a rate of 100,000,000 gallons per acre per day, was maintained. The capacity of each of the sedimentation tanks was 300 gallons to the overflow line, so that one tank alone gave a mean storage capacity of one and one-half hours and the two tanks taken together three hours. During the first series of tests both sedimentation tanks were used. The following table shows the relation of loss of head to the quantity of water filtered, the run in question being a fair average of the five made in this way. The results of all the five tests were practically identical.

PLATE II

B. EXPERIMENTAL FILTER, SEDIMENTATION TANKS, AND MEASURING TANK

A. SEDIMENTATION TANKS AND FLOAT REGULATOR

RELATION OF LOSS OF HEAD TO QUANTITY OF WATER FILTERED

Time.	Elapsed time.	Quantity filtered.	Loss of head.
	Minutes.	Gallons.	Inches.
9.35 A.M.	.	. .	4
9.50 A.M.	15	49	7
10.05 A.M.	30	98	8
10.30 A.M.	55	178	12
1.40 P.M.	55	178	11
2.00 P.M.	75	211	14
2.30 P.M.	105	308	20
3.00 P.M.	135	406	28
3.30 P.M.	165	504	40
4.00 P.M.	195	600	55

Between 10.30 A.M. and 1.40 P.M. test shut down. No liquor.

The maximum loss of head possible was 55 inches. The mean results from the above and four similar tests gave 585 gallons of water filtered before the loss of head was total.

One of the sedimentation tanks was then cut out of service and the period of sedimentation correspondingly reduced to one and one-half hours. Four runs to determine the maximum amount which could be past under the conditions gave a mean result of 575 gallons, in practical agreement with that of the first series. It is apparent that a period of one and one-half hours was sufficient for the removal of that portion of the suspended matter which can be removed by sedimentation. An examination of the water during sedimentation in a glass vessel tended to confirm this conclusion. The suspended matter appears to be of two distinct kinds. One is very finely divided and light and does not settle out even on prolonged sedimentation. The other is granular and heavy and settles rapidly and completely. It was not convenient with the apparatus at hand to reduce further the period of sedimentation. The laboratory experiments quoted earlier in this paper indicated that a period of one hour would accomplish practically the same result as more prolonged sedimentation.

Amount of Wash Water

The pressure on the wash-water pipe line was sufficient to give an upward flow thru the filter of 25 gallons per minute, or about 12 gallons per minute per square foot of surface. In practise, flows of 8 to 10 gallons per square foot per minute were used. After each of the test runs just described, the filter was washt with an amount of water varying from 50 to 100 gallons for two and one-half to five minutes, the wash water being carefully measured. Observations of the surface of the filter showed plainly that the shorter period of washing was sufficient and that the longer periods did not in any case increase the quantity filtered during the succeeding run. The material deposited on the surface was exceedingly light and finely divided, and required but little water for its removal. The stirring device used was not well adapted to the purpose, since there was little penetration of the sand by the suspended material. An air blast or some device which would thoroly agitate the surface before washing would undoubtedly make possible the use of still less wash water. Allowing 50 gallons for each wash, with an average quantity of 575 gallons per run filtered, gives a little less than 9 per cent. wash water.

The loss of head in these tests bears out a fact of general observation, that the loss of head increases at a fairly constant rate during the run. Such being the case, it is quite evident that with a deeper filter the quantity filtered between washings would be proportionately increased. The amount of wash water would, on the other hand, remain constant or increase but slightly. It is therefore safe to say that with a filter having an available loss of head of 9 to 12 feet an average run of six hours or more could be maintained and the amount of wash water could be reduced to less than 5 per cent.

Disposal of Wash Water

The process, as thus far described, is merely one of concentration of the suspended matter. If the above estimate of 5 per cent. of wash water be correct and the filtered water be used for washing, the net result of the process would be the separation of 95 per cent. of the water in comparatively clean form, leaving the total suspended impurity in the remaining 5 per cent. of the water. This water might be spread upon a small area of land to evaporate, it might be evaporated by artificial means, or, if preferable, it might be filter prest; but the most

economical way to dispose of it is to return it directly to the sedimentation tanks. The material on the filter is so prest together into small lumps that it settles rapidly. The problem of the ultimate disposal of the sludge from the tanks will be taken up in another place.

Character of Effluent

Complete chemical analyses of the waters before and after treatment during these experiments were neither desirable nor feasible. The determination of the total organic solids contained in the waters is the only analytical determination which would be of service in estimating the efficiency of the process. This determination might have been made by the usual indirect method, *i. e.*, by the difference between the total and the fixt or mineral solids. That determination is, however, not well adapted to field conditions, and small changes in the organic content would be entirely masked by the relatively large amount of mineral residue present. It was found in the laboratory studies on the waste liquor that estimating the efficiency of the various precipitation methods on the basis of this organic-solids determination, and also on the basis of the oxygen-consumed method, gave practically the same results. In other words, the organic matter present is fairly homogeneous in character, as might well be expected, and the oxygen-consumed figures, altho purely relative, are therefore a reliable measure of the amount of organic matter present. This test, therefore, and the determination of the turbidity, or suspended solids, by the well-known Jackson turbidimeter method, were used in this work to determine the quantity of the organic and the suspended matter, respectively.

During the two three-hour runs samples for analysis were collected every ten minutes from the raw liquor, sedimented liquor, and final effluent, the small samples being mixt together to obtain an average sample for the run. In both cases the rate was maintained at 3.25 gallons per minute. The following data of the test were obtained:

DATA FROM TEST RUN OF FILTER

Test number.	Duration.	Loss of Head.		Quantity filtered.
		Initial.	Final.	
	Hours.	Inches.	Inches.	Gallons.
7	2.9	4	55	566
8	3.0	3	55	585

The chemical analyses for the two sets were very similar. The following table shows the mean values obtained:

ANALYSES OF RAW LIQUOR, SETTLED LIQUOR, AND EFFLUENT

	Parts per million.	Per cent. removed.
Raw liquor.		
Oxygen consumed:		
Total	9,400	. .
Dissolved	2,000	. .
Suspended	7,400	. .
Suspended solids	28,000	. .
Settled liquor.		
Oxygen consumed:		
Total	6,200	34
Dissolved	1,600	20
Suspended	4,600	38
Suspended solids	4,400	84
Effluent.		
Oxygen consumed:		
Total	2,200	77
Dissolved	1,700	15
Suspended	500	93
Suspended solids	575	98

The appearance of the effluent frequently changed materially during the run. Contrary to expectations and general experience, the best effluent was always obtained during the early part of the run. The very first portions of effluent were generally slightly turbid, after which a perfectly clear water came thru, as a rule, entirely free from suspended matter. This state of affairs continued until the loss of head had reached about 6 or 8 inches, when the effluent suddenly became turbid and continued so uniformly until the end. The inference was that under a tension or pull on the surface film represented by about 6 to 8 inches of head the finely divided matter contained in the liquor was pulled thru

the surface and then thru the filter. It was thought that if this should be a correct interpretation of the phenomenon, it might be obviated in one of two ways—by increasing the toughness of the surface deposit, or by decreasing the size of the sand pores by use of a layer of finer material on the surface. Both of these methods were tried.

To increase the density and toughness of the surface film the surface was covered with liquor, the outlet being closed, and 2 ounces of sulfate of aluminum were added and stirred in. Fifteen minutes were allowed for the formation and settling of the precipitate, and the filter was then started. The following data were obtained.

DATA OF TEST RUN OF FILTER AFTER ADDITION OF ALUM

Duration of run	1.9	hours
Loss of head:		
Initial	14	inches
Final	55	inches
Quantity filtered	370	gallons

The chemical analyses resulted as follows:

ANALYSES OF RAW LIQUOR, OF SETTLED LIQUOR, AND OF EFFLUENT AFTER THE ADDITION OF ALUM

	Parts per million.	Per cent. removed.
Raw liquor.		
Oxygen consumed:		
Total	9,000	. .
Dissolved	1,600	. .
Suspended	7,400	. .
Suspended solids	27,300	. .
Settled liquor.		
Oxygen consumed:		
Total	6,000	33
Dissolved	1,600	6
Suspended	4,400	40
Suspended solids	4,500	84
Effluent.		
Oxygen consumed:		
Total	1,800	80
Dissolved	1,600	. .
Suspended	200	98
Suspended solids	450	98

The improvement of this effluent over that obtained without a coagulant is decided, but is hardly sufficient to warrant the extra cost of treatment. Previous studies had shown that it was necessary to add to the volume of waste on the surface of the filter at least 2 ounces of alum in order to bring about a satisfactory precipitation of the lime. Any less amount would not have produced a satisfactory precipitation in a short time. The total quantity filtered during the run was 370 gallons. This gives an amount of sulfate equal to a little over 2 grains per gallon for the entire run, or a consumption of 300 pounds of alum per million gallons. At a cost of 1 cent per pound (based on net weight

of sulfate of aluminum in the crude compound) this would amount to $3 per million gallons of waste, or 10 cents per ton of finished board. This additional cost for chemicals, together with the slightly additional expenditure for labor and water required by more frequent washing, would not seem to be justified in general by the slightly increased purity of the effluent. The results are given here and the cost estimated as a matter of record and in order to show what could be accomplished by the process if it were deemed desirable in any special case.

The second plan for preventing the small suspended particles in the liquor being drawn thru the surface was to use a surface layer of fine sand. A suitable grade of sand was obtained locally and screened thru a No. 20 screen. The sand thus prepared contained a considerable amount of rather fine material. Mechanical analysis showed that it had an effective size of 0.26 mm. and a uniformity coefficient of 2.0.

A 6-inch layer of the sand was placed on the top of the filter and washt. After washing, the surface was examined and found to consist of a well-mixt layer of coarse and fine material. Two runs were made with the filter as thus prepared. The following are the average data obtained:

DATA OF TEST RUN OF FILTER AFTER ADDITION OF FINE SAND

Duration of run	2.3	hours
Loss of head:		
Initial	6	inches
Final	55	inches
Quantity filtered	449	gallons

The appearance of these effluents was such that chemical analyses were not made. They were essentially like the others, and there was no advantage in the use of the layer of fine sand which could in any way offset the obvious disadvantage of the much shorter run.

The Sludge

Amount and Composition.—Thruout the experiments, except for the first few runs, the dirty wash water from the filter was run back into the sedimentation tanks. Eventually, therefore, all the material removed from the waste liquor was accumulated in the bottom of these tanks. At the conclusion of the experiments, which consisted altogether of 12 runs, dealing with a total of 4,900 gallons of the waste, the liquor was drawn off from the tanks as far as possible and the depth of accu-

mulated sludge and remaining liquor was measured. The average depth was found to be 6 inches. After thoro mixing, a sample of the sludge was collected and allowed to stand in a glass cylinder for two hours. From a column of sludge 12 inches in depth a 2-inch layer of clear liquid separated at the top, leaving the depth of sludge on the bottom 10 inches. Therefore the 6 inches of sludge and liquor left in the tank was composed of 5 inches of sludge and 1 inch of water, so that 5 inches represents very closely the average depth of sludge in each tank and will be used in the calculations which follow.

Analysis of the sludge gave the following results:

ANALYSIS OF SLUDGE RESULTING FROM FILTRATION OF STRAWBOARD WASTE

Specific gravity	1.094	
Total solids	19.4	per cent.
Volatile	9.8	per cent.
Fixt	9.6	per cent.

From these data the following results are obtained:

Sludge in tank	78	gallons
Liquor treated	4,900	gallons
Per cent. of sludge (by volume)	1.6	

From 1,000,000 gallons of waste there will be obtained:

Sludge	79	cubic yards
Dry solids	28,000	pounds
Organic solids	14,100	pounds
Mineral solids	13,900	pounds

For each ton of strawboard there will be produced:

Sludge	4.7	cubic yards
Dry solids	1,680	pounds

A glance at Plate I, *B*, will indicate what these figures mean. The piles of straw there shown represent three months' supply for a mill producing 30 tons of board per day. Over one-third of the total weight of this straw will appear in the waste liquor.

Properties and Uses of the Sludge.—As is indicated by the analysis, the sludge is a thick mud. It is dark, muddy brown in color, and has the odor of straw. On exposure to the air it dries much more rapidly than would be expected, owing largely to the action of the air on the free lime. If allowed to dry in a mold, the resulting cast comes away

clear and has taken a very clean impression of the mold. It is very brittle by itself. If, however, a little paper fiber be mixt with it before drying, the dry cast is fairly tough. Such a mixture could undoubtedly be used in many places as a cheap substitute for *papier-maché*.

The dry product had a specific gravity of 0.62. It will readily absorb considerably more than its own weight of water. Its porous nature suggests its use as a heat insulator, particularly in refrigerators.

This material possesses a certain value as a fertilizer. It contains a considerable proportion of calcium carbonate, a substance beneficial to cultivated land. It also contains 0.34 per cent. of phosphoric acid in an available form. Its loose, porous nature makes it particularly valuable for use on clay land, as such land is made much more porous by it and at the same time is sufficiently fine to retain the moisture well. This point was well brought out on examining one of the abandoned settling basins. This basin had originally been diked up about 6 feet above the surrounding fields, and had subsequently been completely filled with the sludge. On digging into this deposit, standing water was observed at a depth of less than 2 feet below the surface, altho the ground water level in the adjacent fields was at least 6 feet lower and the field had not been flooded for over a year.

Some experiments have been made with this solid residue as a base for the production of a sulfur dye. Fusion of the substance with twice its weight of a mixture of one part of sulfur and two of sodium sulfide yields a mass containing a considerable proportion, perhaps 20 per cent., of a brown sulfur dye. Purification of the resulting dye from the mass of inert material was not attempted, and further study is required to determine the most satisfactory procedure for the preparation and purification of this dye, but enough has been done to indicate that a low-grade sulfur dye can be made from this waste material. It dyes unmordanted cotton a good warm shade of brown, is fast to hot soap and to sunlight, and compares favorably in color and fastness with dyes on the market selling at 15 cents per pound.

Considerable attention has been given to the problem of finding profitable use for the residual organic matter which is the end product of the filtration processes here recommended. Altho the satisfactory solution of this problem would be highly desirable and would at once assure the treatment of all strawboard waste liquors, it must be remembered that this is merely a question incidental to the main problem. It is believed that the process of sedimentation, followed by mechan-

ical filtration, essentially as described, furnishes by itself a solution of that problem which will prove of financial advantage to the manufacturers and of lasting benefit to all who have an interest in the purity of the streams below. It was therefore not deemed pertinent to the present investigation to pursue further the question of the utilization of the sludge. The suggestions here given, and particularly that in regard to the preparation of a dye, are merely intended to indicate the direction in which, according to the writer's views, future research would bring results of value.

Résumé of Method of Treatment

The following plan of treatment is recommended: The waste water from the beaters should be past thru a properly designed settling tank of such size that it will give a period of about one hour's storage. A tank built on the principle of the Dortmund tank would be preferable to any other, owing to its compactness and the possibility of continuous use. The tank should have a capacity of approximately 1,200 gallons for each ton of board produced per day by the mill.

The water should pass from the tank directly to the filters, which should be built in small units. The filters should have an available loss of head of at least 12 feet, and could be run at a rate of 100,000,000 gallons per acre per day. This would necessitate a filter area of approximately 16 square feet per ton of board produced daily. This figure allows 10 per cent. excess for repairs and washing.

The effluent should be pumped and used again for washing the filter and for beater wash water. It would at all times contain less impurity than does the very last water past from the beaters, and its use during the early part of the washing process could do no possible harm. To insure a proper washing out of the last of the lime from the stock, it would probably be found necessary to complete the washing with fresh water. In any case a saving of one-half to two-thirds of the amount of wash water now used could be realized, the amount of waste liquor being correspondingly reduced. The water used in washing the filter should be returned to the sedimentation tank, and would require no further treatment.

The sludge from the sedimentation tank could be most expeditiously dealt with by filter pressing. There would remain a fairly dry and hard press cake, which would require disposal unless some profitable

use for it be found. Under the influence of the air and sun this material is speedily resolved into mineral matter, forming a sort of soil. It could be spread upon low land in thin layers and would then take care of itself.

Instead of being filter prest, the sludge might be discharged upon small areas of sandy soil where such are available or even upon somewhat larger areas of less porous soil, and allowed to dry out by draining and evaporation. The dry layer of sludge could then be removed and disposed of. No accumulation of the wet material should be allowed. When once dried out and subjected to the action of the sunlight and air it soon becomes harmless, but in deep beds and constantly covered with water it is subject to all the offensive putrefaction described in the case of the sedimentation fields. This process of spontaneous draining and drying out would probably be found the cheaper, but would require a considerable area of suitable land and would also involve more careful supervision. The amount of land required would depend wholly on the quality of the drainage. For average conditions it may be roughly estimated at 1,000 square feet per ton of board produced by the mill daily. The dried sludge would require removal before the application of more sludge.

Character of Waste Water after Treatment

The quality of the effluent from the proposed process is not all that could be desired. In spite of the fact that it is possible to remove over 90 per cent. of the suspended organic matter present in the liquor, the resulting effluent is still putrescible. That is, a bottle of the liquor shut up air-tight and kept at a warm temperature will in the course of a few days undergo putrefactive fermentation. The putrefaction is rather slow, however, and not offensive. In admixture with an equal volume of tap water the effluent does not putrefy even when inoculated with a small amount of sewage.

The fact that the effluent is practically free from gross suspended solids—that is, solids which will settle out on the bed of the stream—is of greater significance than the analytical data. As was pointed out in the earlier discussion of the problem (page 8), by far the greater part of the damage done to the polluted streams is brought about by the deposit of material in the stream beds. The effluent which has past the treatment here outlined will contain no material capable of settling out even in slack water.

The conclusion is therefore justified that the discharge of this effluent into a stream whose minimum flow equals in volume the flow from the mill would not produce a nuisance. With no allowance for a possible diminution of the amount of wash water, if used as suggested above, this means that the minimum stream flow must be at least 0.05 cubic foot per second per ton of board produced daily at the mill. A minimum flow of 0.1 cubic foot per second per daily ton would therefore provide for a generous factor of safety if the stream is reasonably unpolluted at the point of discharge.

The discharge of such an effluent into a stream highly polluted with sewage would probably be accompanied by an aggravation of the conditions already existing. There would, as usual, be a precipitation of the sewage material by the lime of the effluent. In all fairness it could be maintained that the organic matter of the effluent was not contributing to the nuisance. If, therefore, it should be decided that the addition of lime to a sewage polluted stream constitutes a nuisance, further treatment of the effluent would be required to remove this caustic lime. If, on the other hand, as would seem to be reasonable, it should appear that the real pollution of the stream lay in the sewage and the lime was incidental and was there by right, there would be no reason for such further treatment.

Cost of the Process

The cost of the process recommended cannot be discust in detail at this time. It would be largely the cost of installation. The design and construction of a suitable plant require expert attention, and the cost of the plant would depend somewhat on local conditions. The cost of maintenance would be slight. The cost of additional pumping to supply wash water—say 5 per cent. more than the present amount pumped—can be determined readily. The services of one man, who could also assist in the mill part of the time, would be a sufficient addition for running the plant. The power necessary to pump the sludge thru the filter presses, if that plan were adopted, would not be noticeable in comparison with the total power used in the mill. If the sludge were disposed of by the other plan, evaporation and drying in the field, the services of another man would be required.

In conclusion, the following summary of the chief points of the present paper may be made:

SUMMARY

The present method employed for the treatment of strawboard waste liquor, that of sedimentation in large fields, is unsatisfactory and expensive and proceeds on a wrong principle.

The filtration of the liquor thru sand, so-called mechanical filtration, but without coagulants, after a short period of sedimentation will remove 93 per cent. of the suspended organic solids and 98 per cent. of the total suspended matter determined as turbidity.

Actual experiments have shown that the resulting effluent can be discharged into an equal volume of reasonably pure water without creating a nuisance. In particular, there will be no sedimentation of organic matter. If its discharge into a seriously polluted stream should bring about precipitation of sewage matter and consequent nuisance, the blame should in all equity be fixt on those contributing the sewage.

The sludge resulting from the sedimentation tanks, after pressing or spontaneous drying, is innocuous and makes good soil. It has some value as a fertilizer and is particularly valuable to mix with the clay soils of the Middle West to render them more porous. Other uses for this material are suggested, but they require further study.

The cost of the entire process is sufficiently low to admit of its adoption wherever stream pollution is serious.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

STUDIES OF SEWAGE DISTRIBUTORS FOR TRICKLING FILTERS

BY C.-E. A. WINSLOW, EARLE B. PHELPS, C. F. STORY, AND H. C. MCRAE

I. THE GENERAL PROBLEM OF SEWAGE DISTRIBUTION

THE chief technical difficulty in the construction of the trickling, or percolating filter, as it is called in England, lies in securing efficient distribution of the sewage. The liquid must be discharged slowly and evenly over the whole surface of the bed and thoroughly aërated in the process; in other words, it must be distributed in a rain of fine drops. The mechanism adopted differs widely in various disposal plants. Some of the earlier English investigators used tipping buckets and troughs, placed at intervals over the filter, relying on the splash to dose the intervening areas. This method must necessarily produce imperfect results, and the required apparatus is cumbrous and expensive. Other devices are designed to secure a steady overflow from fixed level troughs or pipes. Of these, the most highly developed is the Stoddart distributor, in use at Horfield and other English towns. This is practically a series of channels over the sides of which the sewage overflows continuously, dripping from points on the under side, 360 points being allowed to a square yard. Theoretically this should secure a very even distribution; but the system requires that the channels remain perfectly level and clean, a condition difficult to preserve in practice.

Another series of distributors secures an even spread of the sewage by the use of some form of moving apparatus. The simplest devices of this type consist of a pair of revolving arms discharging sewage in opposite tangential directions, so that they are propelled by their own discharge on the principle of a Barker mill. The Candy-Whittaker

patents cover some of the best known English distributors of this type. More elaborate designs involve the use of power for moving troughs from which the sewage trickles by numerous small openings, or from which it flows in a thin stream over a weir. In connection with the experiments carried out at Birmingham, Scott-Moncrieff installed a large distributor of this pattern, which consisted of a trough revolving on a circular rail at its outer extremity and driven by a small oil engine. At Hanley is a similar trough, which runs back and forth over a rectangular bed, propelled by an electric motor.

There are certain inherent objections to all such movable distributors which have so far seemed almost insuperable to American engineers. Power, or its equivalent hydraulic head, is necessarily involved in all of them. Movable arms and troughs involve structural details which are expensive to construct and which require constant attention; and it may seriously be doubted whether devices of such complexity and delicacy of adjustment could be operated at all under the influence of a severe winter climate. Even in England trouble was experienced at certain plants during the cold winter of 1906–07.

The simplest and most practical of the English methods of distribution is the system of spraying the sewage upward from sprinkler heads arranged at intervals along fixed pipes. Fixed sprinklers of this type have been used for some time at Salford and other English towns, and are planned for the two largest trickling filter plants yet designed in the United States — at Columbus, Ohio, and Waterbury, Connecticut.

The chance of offensive odors is of course increased by the distribution of sewage spray in the air, but the free oxidation probably facilitates purification. At Birmingham a careful comparison has been made of various types of revolving distributors and pressure nozzles. Mr. J. D. Watson reports (*Engineering News*, **58**, 89), as a result of these studies, that spray jets cost $2,500 per acre to install, against $5,000 to $20,000 for moving distributors, and that the beds equipped with the latter were idle as a result of the distributor being out of order from 8 to 28 per cent. of the time. The results obtained with fixed sprinkler heads of course depend largely on the details of their construction, the head available, the spacing of the nozzles, and particularly on the construction of the nozzles themselves.

In the course of the investigations on the purification of the sewage of Boston, carried out at the Sanitary Research Laboratory of the

Massachusetts Institute of Technology, another method, that of gravity distribution, has been devised.

This system, referred to in an address before the Society of Arts, October 12, 1905, and described in the *Engineering News* for August 16, 1906, appears to possess certain distinct advantages. The sewage is distributed in troughs elevated over the filter, from which it drops through holes in the bottom of the troughs onto concave disks below, splashing upward from the disks in a fine spray. It has been used for two years with success at the Boston station, and has since been adopted by the Massachusetts State Board of Health for an experimental filter at Andover, according to an account published in the *Engineering News* of April 11, 1907.

With distributors of almost any type it is possible to combine siphon tanks or other automatic devices for securing intermittency of operation. The increased pressure thus produced at the moment of maximum discharge tends to keep clear any openings which might otherwise clog, and when the sewage is discharged under pressure from perforated pipes the variations in head tend to make the circle of spray both wider and more even. This plan has long been used at Chesterfield and other English towns.

II. Methods for Measuring the Efficiency of Sewage Distributors

The Stoddart distributor and the various types of movable sprinklers used in England are theoretically perfect, and their failure, when it occurs, is due to structural imperfections or lack of care in maintenance. On the other hand, fixed sprinkler nozzles and the gravity system of distribution cover at best only a portion of the surface of the filter. Since both these latter types discharge sewage approximately in a circle, each nozzle or disk will wet only 78 per cent. of the square area surrounding it. Furthermore, almost all these distributors tend to discharge, for the most part, in one or two concentric rings of the wetted area. Some nozzles, too, discharge unevenly along different radii. It is important to determine how serious these deviations are. Imperfect distribution means that a part of the filter area below is wasted and another part is operated at excessive rates. Yet almost no exact data upon this point are now available. Some experimenters have noted the proportion of the total area wetted by their

sprinklers; but such a standard is, of course, wholly inadequate, since it fails to discriminate the extent of the discharge upon different portions of the wetted area. We have therefore thought it worth while to make a somewhat extensive study of this point, comparing in detail the efficiency of various fixed sprinkler nozzles and of a number of patterns of gravity distributors under various conditions.

For the quantitative study of the efficiency of distribution a meas-

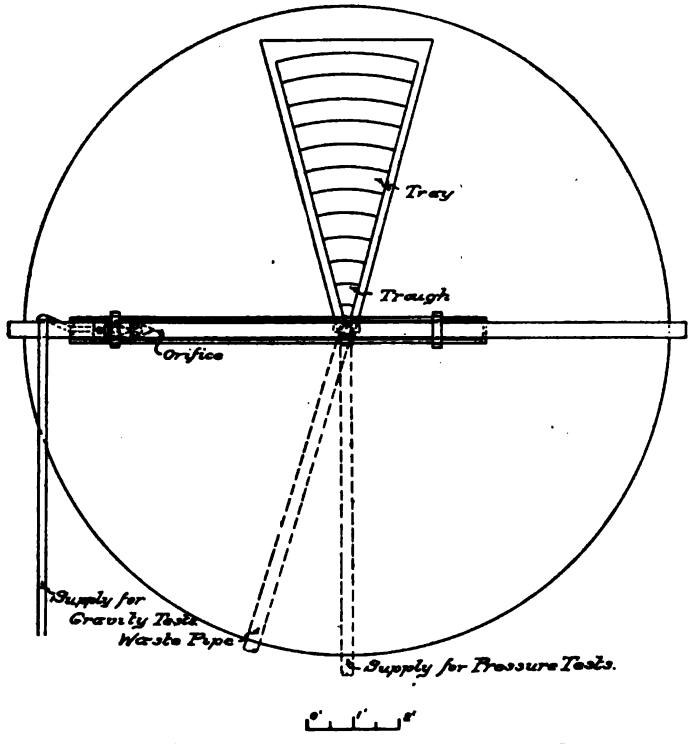

FIG. 1.—PLAN OF APPARATUS FOR SPRINKLER TESTS

uring apparatus was devised, the construction of which is indicated in Figures 1 and 2. It consisted of a shallow, circular basin of cement concrete 14 feet in diameter, sloping toward a central drain connected with a waste pipe below. A 2-inch supply pipe passed under the concrete and rose through this drain at the centre of the basin. To this pipe were attached the sprinkler nozzles of various types designed for pressure distribution. A wooden platform in the shape of the 30° sector of a circle was attached at its pointed end to a 2½-inch

iron collar, fitted over the supply pipe so as to turn freely upon it. The outer end of the wooden platform was supported on ball-bearing castors, arranged to run on a flat shelf at the periphery of the concrete basin, so that the whole platform could be revolved about the supply pipe as a centre; and the collar and castors were so adjusted that the platform

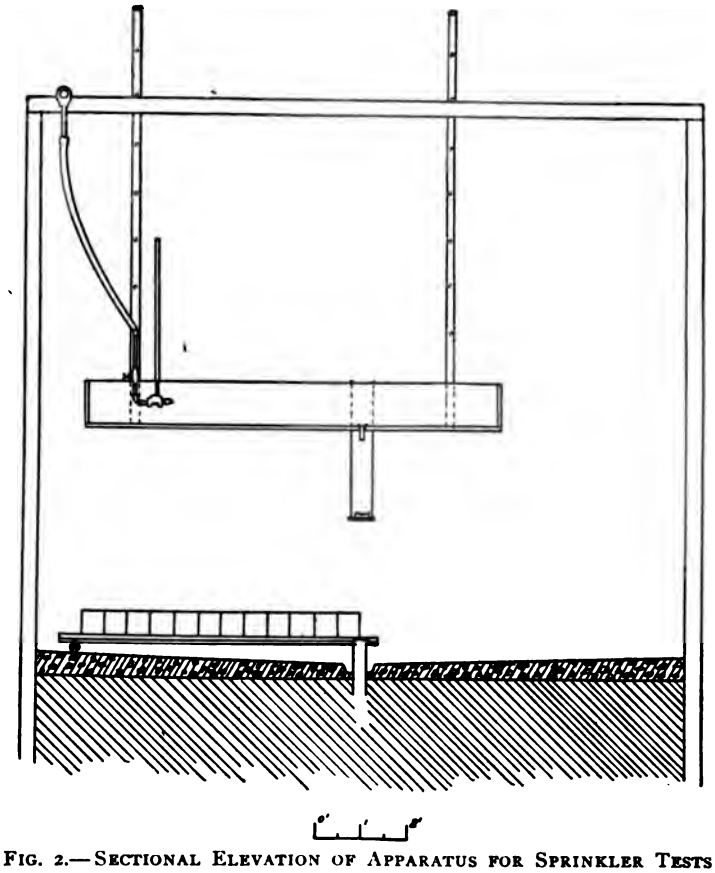

FIG. 2.—SECTIONAL ELEVATION OF APPARATUS FOR SPRINKLER TESTS

was exactly level. The platform carried a galvanized iron tank, also in the form of a 30° sector, divided into compartments by concentric arcs 6 inches apart. The radius of the tank was 6 feet, giving twelve concentric compartments, and its depth was 6 inches. When this tank was rotated about the supply pipe during the course of an experiment, the evenness of distribution was of course measured by the

relative amount of liquid collected in the respective compartments. In various stationary positions the trough recorded radial inequalities.

The supply pipe at the centre of the basin was connected at its outer end with an upright stack of 2-inch pipe made up of short lengths, any desired number of which could be used. At the top of the stack was a wooden box, fed by a hose and relieved by an overflow just below the top. The difference between the water level in this box (varied by removing sections of pipe from the upright stack) and the level of the sprinkler nozzle at the centre of the basin represented approximately the total head effective in distribution. The rate of flow was of course fixed by the head and the sprinkler nozzle used. It was estimated in each test from the total discharge into the measuring tank, and from the time occupied by the run.

The apparatus as shown in Figures 1 and 2 was adapted for the study of gravity distributors by the addition of an overhead trough. This was hung from two timbers passing diametrically across the basin, supported at their extremities by upright studs. At a point fixed over the centre of the apparatus a ¾-inch brass orifice in the bottom of the trough allowed the liquid to discharge upon the splashing disk below.

The uprights supporting the trough were fixed to the cross-timbers above by movable iron pins and the uprights were pierced for the reception of these pins at intervals of 1 foot, so that the distance between the trough and the measuring tank below could be varied at will. The distance between the level of the water in the trough and the top of the tank measured the total head available for gravity distribution. In this system, however, there is another variable. With a given total head, the distance between the point of discharge and the splashing disk and the distance from the splashing disk to the filter may be mutually varied. In our experiments this was provided for by supporting the various splashing disks tested upon a circular lead plate, 6.5 inches in diameter, hung from the distributing trough by four wires. Varying the length of these wires altered the portion of the total head above the splashing disk (called for convenience "head-on-sprinkler").

The rate of flow with this type of distributor is, within limits, independent of the head, so that the rate also had to be taken into account. The rate of discharge was equal to the rate of supply of liquid to the trough, and this supply was measured through a calibrated orifice, indicated in Figures 1 and 2. Two orifices were used in the experiments, one $\frac{7}{16}$ inch and one ⅝ inch in diameter. The orifice plug in

use was connected to a 2-inch tee by a reducing coupling. The section of the tee was large enough to permit an accurate measurement of the static head on the orifice by a glass piezometer tube inserted in its top, and the head was adjusted at any desired point by a valve behind the tee.

The orifices were calibrated by measuring their discharge at various heads in a cypress tank, 2 feet by 6 feet in area and 3 feet deep. A special form of gauge, to be described later, was used in these measurements, and they were accurate within .005 inch in the depth of the tank, or .005 cubic foot of discharge. The calibration of the $\frac{7}{16}$-inch orifice is shown in Table I.

TABLE I — CALIBRATION OF ORIFICE

Head on $\frac{7}{16}$-inch orifice.	Q in cubic feet per minute.	Q in gallons per minute.
Inches.		
5	.228	1.71
6	.240	1.80
7	.256	1.91
8	.276	2.06
9	.289	2.16
10	.306	2.29
12	.330	2.47
14	.354	2.65
16	.378	2.83
18	.400	3.00
20	.420	3.15
22	.438	3.28
25	.468	3.50
36	.546	4.08

The discharges of 1.71 and 4.08 gallons per minute, corresponding to 5-inch and 36-inch heads on the orifice, were chosen as two arbitrary rates of discharge for the gravity distributor tests. The $\frac{5}{8}$-inch orifice was tested sufficiently to find a third, higher rate. A head of 18 inches on this orifice was found to give a discharge of 1.1325 cubic feet, or 8.47 gallons per minute, and this was used as the standard rate for high discharges. The entire apparatus was protected during the course of the experiments by a rough wind shield.

The measurement of the volume of liquid collected in the various compartments of the measuring tank during a test was, according to

our original plans, to be made directly, and for this purpose a small stopcock was attached to each compartment. This process proved somewhat tedious, however, and the same end was attained by measuring the depth of the liquid in each compartment at the end of the run, after a careful preliminary calibration of the various compartments.

The depth of water in this measuring tank, and in the cypress tank used for nozzle calibration, was measured by a simple and accurate gauge devised for the purpose, the construction of which is indi-

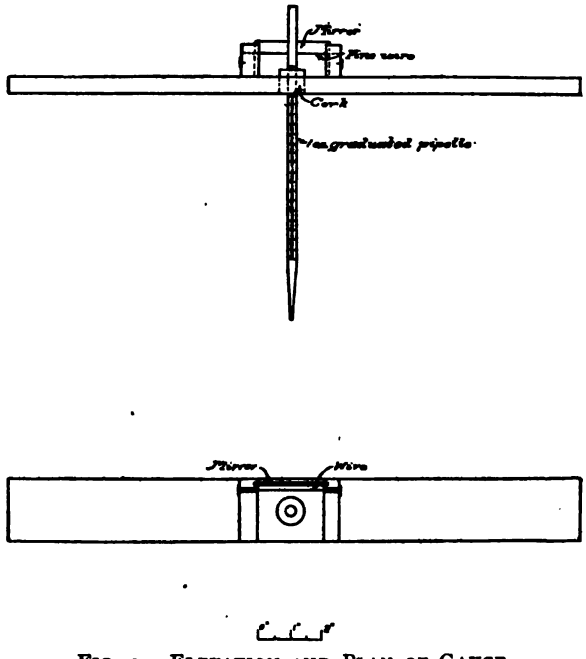

FIG. 3.—ELEVATION AND PLAN OF GAUGE

cated in Figure 3. It consisted of a graduated glass tube (a 1 c.c. pipette), the graduated portion being 6 inches long and divided into hundredths. This tube slid up and down in a cork fitted into a long, flat piece of wood, carefully planed. When the wooden crosspiece rested in a horizontal position, supported at its ends, the tube between was exactly vertical. Just above the wooden crosspiece a fine wire was stretched longitudinally between two supports behind the tube, and behind the wire a small mirror was fixed. By reading with the wire and its reflection superposed the position of the tube could be estimated to tenths of its smallest graduations (.0005 foot). In measur-

ing the depth of water in a compartment of the measuring tank the wooden crosspiece of the gauge was rested on the two sides of the tank and the tube was slid carefully down till its mouth just touched the surface of the water. This point could be detected with great accuracy by the jump into the tube of the drop of water drawn up by capillary action.

Each compartment of the measuring tank was calibrated by pouring in measured quantities of water and reading the depth after the addition of each successive portion. The average of these determinations gave the number of units of depth corresponding to a given volume of water. The reciprocal of this was the volume of water corresponding to a unit of depth for the compartment in question. A special correction was necessary for irregularities in the bottom of the tank and for the zero reading of the gauge. The former was determined by the difference between the change in level produced by the first portion of water poured in and by subsequent portions. The general results of this tank calibration are indicated in Table II.

TABLE II — CALIBRATION OF MEASURING TANK

Compartment.	Change in depth for one liter added.*	Bottom correction.	Liters per unit change in depth.†	Gallons per unit change in depth.	Relative value (area).
1	.268	+.020	.933	.246	1.0
2	.187	. .	2.674	.706	2.87
3	.220	—.017	4.545	1.200	4.92
4	.158	—.009	6.329	1.67	6.80
5	.120	—.008	8.333	2.20	8.96
6	.101	—.017	9.901	2.61	10.6
7	.084	—.017	11.90	3.14	12.8
8	.074	. .	13.51	3.57	14.6
9	.065	—.015	15.38	4.06	16.6
10	.059	—.014	16.95	4.47	18.2
11	.052	—.027	19.23	5.08	20.7
12	.048	—.013	20.83	5.51	22.4

* Half a liter for compartment No. 2; quarter of a liter for compartment No. 1.
† Unit = .5 foot.

The "relative values" in the last column of the table should, of course, have come out 1, 3, 5, 7, etc., if there had been no irregularities in the construction of the tank, for with unit depth:

$$Q_1 = \frac{\pi \times 1^2}{4} \times 1 = \frac{\pi}{4}.$$

$$Q_2 = \frac{\pi \times 2^2 \times 1}{4} - \left(\frac{\pi \times 1^2}{4} \times 1\right) = \frac{3\pi}{4} = 3Q_1.$$

$$Q_3 = \frac{\pi \times 3^2 \times 1}{4} - \left(\frac{\pi \times 2^2}{4} \times 1\right) = \frac{5\pi}{4} = 5Q_1.$$

The testing apparatus in operation is shown in Figure 4, and nearer views of the measuring tank in Figures 5 and 6. The following memo-

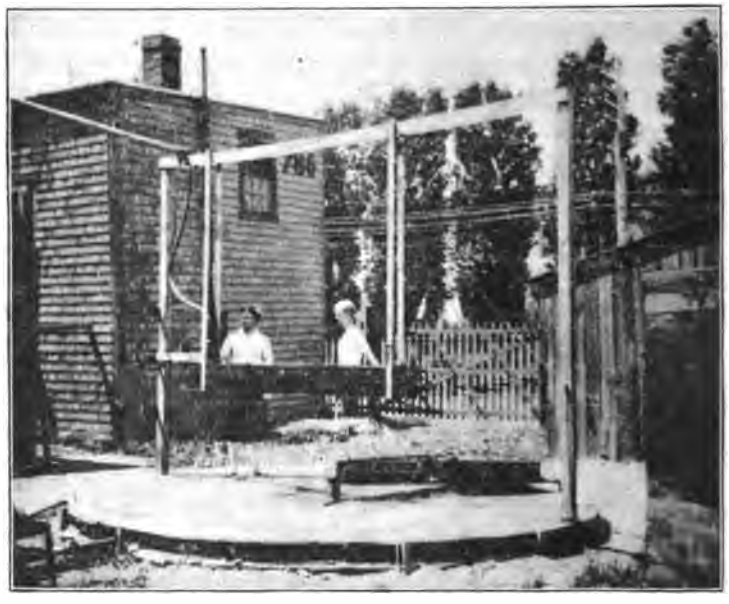

FIG. 4.—GENERAL VIEW OF TESTING APPARATUS WITH TEST IN PROGRESS

randum of the routine procedure in making the test of a gravity distributor may make the working of the whole apparatus somewhat clearer. In beginning a run the measuring tank was emptied, put in place on the wooden platform, and covered with a cover of tar paper stretched over slats. The desired total head was adjusted by raising or lowering the trough, and the head on the sprinkler was regulated by means of the wires suspending the lead plate from the trough. The disk to be tested was then centred on the lead plate just below the ¾-inch opening in the bottom of the trough. The valve supplying the trough was then opened and regulated till the desired discharge was registered on the

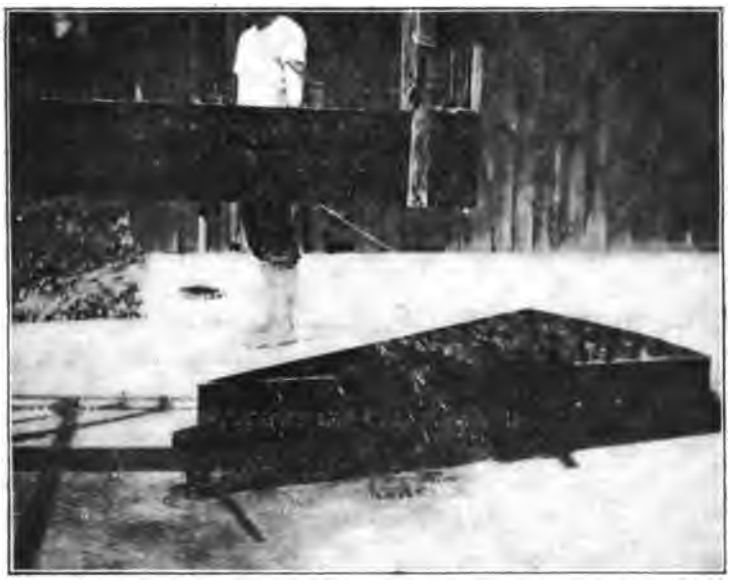

FIG. 5.—SIDE VIEW OF MEASURING TRAY WITH TEST IN PROGRESS, SHOWING TROUGH AND DISTRIBUTING DISK IN PLACE

FIG. 6.—VIEW OF MEASURING TRAY FROM ABOVE. TEST IN PROGRESS

piezometer tube. After conditions had become constant in the trough, the cover of the measuring tank was removed (the time being taken with a stop watch). During the test the tank was slowly rotated by hand. As soon as any compartments became so full as to threaten splashing the test was stopped, the cover replaced, and the time again noted. The supply valve was then closed, and after the discharge had ceased the cover was removed and the depth of liquid in each compartment of the measuring tank was determined, as described above.

III. Method of Calculating a Coefficient for the Efficiency of Sewage Distributors

After the proportionate amount of discharge in various zones about the distributors had been determined by the method outlined above, it was necessary to devise some method of stating the results so that the efficiency of the various types could be easily and accurately compared. For this purpose one of us (E. B. P.) has derived a "coefficient of distribution," which shows the mathematical relation between any observed condition of distribution and that ideal condition in which each small unit of area should receive its exact proportionate share. Professor Phelps' calculations were published in the *Engineering News* of October 11, 1906, and in the Technology Quarterly for March, 1907 (**20**, 34). The following quotation outlines his method:

"For the purposes of this problem let us assume that a pressure sprinkler is shooting up a spray of sewage fountain-wise, the sewage falling over a circular area. Along any radius let us place a line of small, square collecting tanks of known areas, which we may designate the unit area. Let it be assumed, further, that the distribution along this radius is the mean of that along all radii. The variations along the various radii will be small, and the assumption may be completely realized, as is being done in our experiments, by revolving the line of collecting tanks about the centre during the experiment. After running a suitable length of time, the sewage is shut off, and the amount collected in each small tank is measured. In the accompanying table a set of actual results is reproduced for the sake of illustration.

TABLE III—RESULTS OF OBSERVATIONS OF DISTRIBUTION EFFECTED BY SEWAGE SPRINKLER

Tank No.	Radial distance (D).	Sewage quantity (Q).	D × Q.	Excessive quantities (Ex. Q).	D × Ex. Q.
1	0.5	0.8	0.4	. .	. .
2	1.5	1.6	2.4	0.14	0.21
3	2.5	2.7	6.8	1.24	3.10
4	3.5	2.5	8.8	1.04	3.65
5	4.5	2.3	10.3	0.84	3.78
6	5.5	1.9	10.4	0.44	2.43
7	6.5	1.5	10.0	0.04	0.26
8	7.5	1.3	9.8	. .	. .
9	8.5	1.0	8.5	. .	. .
10	9.5	0.6	5.7	. .	. .
Totals	50.0		73.1		13.43

$73.1 \div 50.0 = 1.46 = M.$

"In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being proportional to the volumes. Now if these quantities, Q, are plotted as ordinates against the corresponding D values as abscissæ, we obtain a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram (Fig. 7). It shows the rate of discharge per unit area at any point whose distance from the centre is known, and will be known as the curve of radial distribution. Since the radial distribution measured was assumed to be the mean of all radial distributions, the ordinate of this curve at any given distance from the centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i. e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing,

relatively, by the radial distance of the point in question. In column 4, D × Q, in the table are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the correspond-

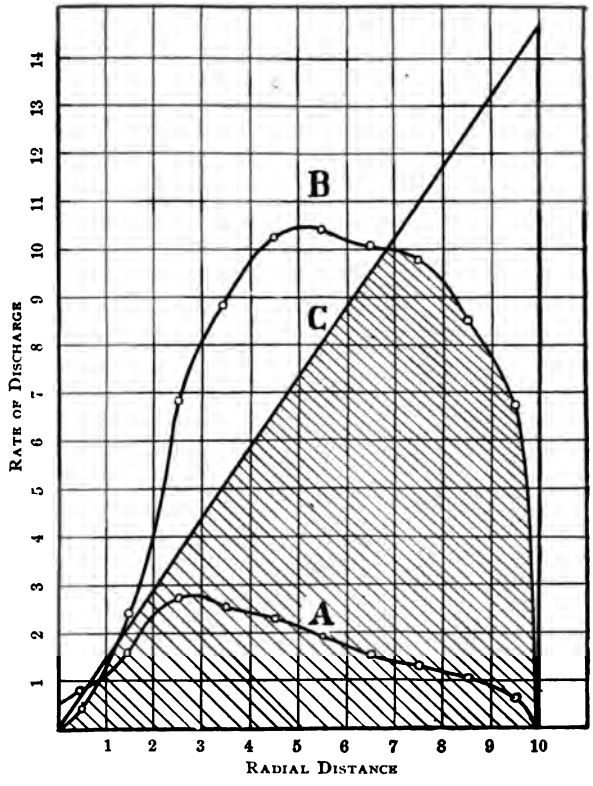

Fig. 7.—Diagram of Distribution

A. Curve of radial distribution. B. Curve of distribution over the circle. C. Curve of perfect distribution over the circle.

ing D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

"From its construction this curve has the following properties: The ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre;

the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

"It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i.e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter, and from the known base of the triangle its altitude may be computed. It may be calculated more readily but less accurately by adding up the column $Q \times D$, and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

"We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the more nearly will the two curves coincide, and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

"If we define the term 'excessive discharge' as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form,

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or, more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

"Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities Q × D, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coördinate lines vertical, as usual, and the other set radiating from the origin. Direct plotting of the figures used in curve A upon such paper will in reality give curve B, any given value having an actual magnitude upon the plot which is proportional to the horizontal distance from the origin."

While the plot and the foregoing demonstration are essential to a clear understanding of the coefficient, it has been found much simpler and sufficiently accurate in practice to make an arithmetical calculation of the coefficient directly from the observed data. Either of the last two columns in Table II may be used instead of column 2, D, in Table III, since it corresponds to it with an allowance for the irregularities of construction in the tank. For column 3, Q, the observed depth is used, after the application of the proper bottom correction. The sum of the fourth column, D × Q, gives the total discharge, T, upon the sector tested, directly in gallons, if the relative value in gallons is used for D. The sum of column 2, D, corresponds to the total wetted area; that is, it bears the same relation to the total area that the sum of the fourth column, D × Q, does to the total discharge. In practice, when the liquid discharged did not reach the outer compartments, those zones not wetted were of course omitted from column 2. Now if the sum of column 4, D × Q, be divided by the sum of column 2, D, the quotient, M, will be the mean discharge per unit area over the whole wetted surface. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in Table III in column 5, under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total exces-

sive discharge as already defined, E. In practice, the difference between the mean discharge and the actual discharge was also determined for the zones which received less than their share; and the sum of these values was used as a check on the total excessive discharge, E.

Either the total excessive discharge on the areas receiving too much liquid, or the total deficient discharge on the areas receiving too little, when divided by the total discharge measures the deviation of the distribution from a perfect condition. Referring to Figure 7, it will be seen that the total discharge, T, corresponds to the area under the line C, and that the excessive discharge, E, corresponds to the area below B and above C. Perfect distribution would be indicated by a value of zero for E or a coincidence of lines B and C. This condition is called unity, and the observed condition in any case is expressed as the difference between unity and the ratio of excessive discharge to total discharge. In the shape of a formula this becomes,

$$\text{Dist. Coef.} = 1 - \frac{E}{T},$$

and in the illustrative example given in Table III,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The crude coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true corrected coefficient based upon the total area of the filter, including the unwetted corners between the circles. Each wetted area should be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the corrected coefficient, C, may be found from the crude coefficient, c, by the formula,

$$C = c \times \text{Cir/Sq}.$$

This correction will, of course, diminish the crude coefficients to less than 78 per cent. of their value for the wetted area, and all coefficients recorded in our investigation are calculated upon this basis of arrangement in squares. In practice, however, it would be of advantage to arrange distributors, not along two axes at right angles to each other, so that each is at the centre of a square, but on three axes inclined at 120°, so that each is at the centre of a hexagon. With distributors at the centres of squares, the waste area, with no overlap-

ping, amounts to 21.5 per cent. of the whole. With distributors at the centres of hexagons, the waste area amounts to only 9.9 per cent. The hexagonal arrangement makes it possible to put 343 sprinkler heads on an acre instead of 303, spaced with 12 feet between centres, and to raise a rate of 2,000,000 gallons to 2,270,000 without increasing the discharge upon any portion of the wetted area.

IV. Determination of Coefficients for Gravity Distributors

The system of gravity distribution involves the discharge of the sewage from openings in the bottom of troughs onto concave disks placed below, the discharged stream having sufficient force to splash up and out from the disks in a fine spray.

The splashing disks first used on the Technology trickling filter in 1905 were of metal, 3 inches in diameter, and with a concavity corresponding to a radius of curvature of 6 inches. These were at first placed only 5 feet apart, with a discharge on each disk of less than .9 gallon per minute. This discharge proved too low for good distribution, and a single disk was substituted for four on each 100 square feet in area, giving 10 feet between disks and a discharge on each of 3.47 gallons per minute. This proved far more satisfactory, and the experimental filter thus equipped gave very satisfactory results even through the severe winter of 1906-07. The performance of one of these disks in operation is shown in Figure 8.

With gravity distributors there are three distinct variable factors, the rate of discharge, the distance between the trough and the disk, and the distance between the disk and the filter below. In our experiments we have varied all three independently. For rates we have used the three standard discharges described above, corresponding, respectively, to 1.71, 4.08, and 8.47 gallons per minute. For the total head between the trough and the measuring tank (corresponding to the filter surface) three standard heads were used, 2 feet, 4 feet, and 6 feet; and with each of these total heads three different positions of the disk were tested. With the 2-foot total head the head-on-sprinkler was made 6 inches, 12 inches, and 18 inches; with the 4-foot total head the head-on-sprinkler was made 1, 2, and 3 feet; with the 6-foot total head the disk was placed at 1, 2½, and 4 feet.

Besides these three variable factors the efficiency of gravity distribution depends upon the design of the splashing disks themselves.

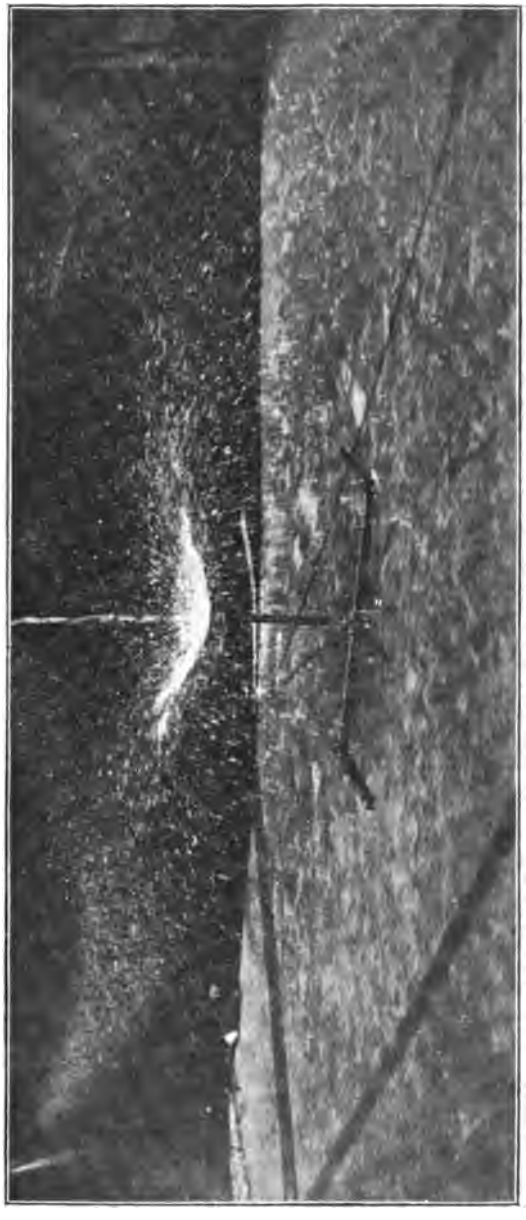

FIG. 8.—VIEW OF GRAVITY DISTRIBUTOR IN OPERATION

Twenty-three types of disks were tested in our experiments, varying in size and curvature, in the hope of finding some more favorable design than the simple concave type first used. Cross-sections of the disks examined, with their respective dimensions, are shown in Figure 9.

Nos. 1 to 4 were wooden disks 2 inches in diameter, with surfaces of different degrees of concavity varying from a radius of curvature of 4 inches to one of 20 inches. Nos. 5 to 10 were disks 3 inches in diameter, Nos. 6 and 7 of metal and the rest of wood, the radii of curvature of their concave surfaces varying from 2 to 20 inches. Nos. 11, 12, and 16 were larger, very shallow wooden disks. Nos. 13, 14, 17, 18, and 19 were wooden disks whose upper surfaces were concave about a central raised point, rising again all around their outer edge. We have called this design the mushroom disk. No. 15 was a large, deep metal disk, 5 inches in diameter, and with a 3-inch radius of curvature. Finally, Nos. 20, 21, 22, and 23 were large, 6-inch wooden disks with radii of curvature varying from 4 to 20 inches.

Since each of these twenty-three disks was tested under twenty-seven standard conditions (three subdivisions of each of three total heads at three rates), making over six hundred tests in all, it has not seemed best to publish the mass of figures obtained in detail. The final corrected coefficients are given in Tables IV, V, and VI, arranged first according to the rate of discharge on each disk and then according to the head.

It must be remembered, of course, that the corrected coefficients in these tables take account both of the extent and the evenness of the circle of spray. Some of the disks produced good distribution within a small circle, but the rate on the wetted area was so great as to be excessive. By reducing the crude coefficients for such disks so as to bring the total rate down to 2,000,000 gallons per acre per day, the corrected coefficients have been estimated. This was done for the three rates of discharge tested as follows: A discharge of 1.71 gallons per minute on each splashing disk corresponds to 2,480 gallons per day per disk. At a 2,000,000-rate this requires 808 sprinklers per acre, or one sprinkler to each 54 square feet of filter area; the distance between sprinklers must therefore be 7.35 feet. Similarly the 4.08-gallon rate would require 341 sprinklers per acre, or one to each 128 square feet, and the distance between sprinklers must be 11.3 feet. The 8.47-gallon rate calls for 164 sprinklers per acre, or one to 266 square feet, with a distance of 16.3 feet between sprinklers. All coefficients in the

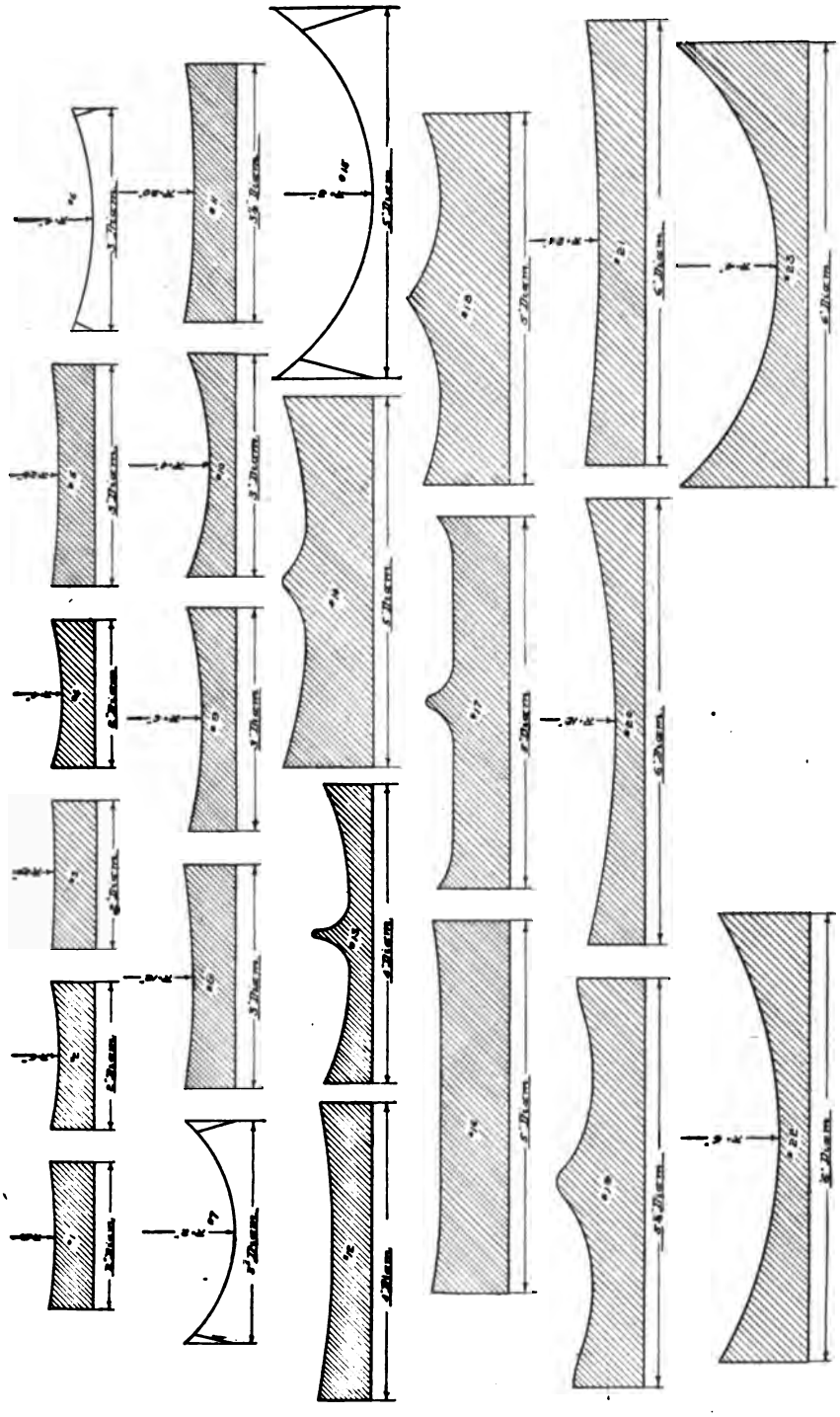

FIG. 9.—CROSS-SECTIONS OF SPLASHING DISKS

TABLE IV — CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 1.71 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

Total head in feet.	Head-on-sprinkler, feet.	Number of Disk.																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	0.5	.05	.07	.05	.05	.01	.02	.05	.01	.04	.05	. .	.02	.02	. .	. .	.02	. .	. .	. .	. .	. .	. .	. .
	1.0	.10	.11	.06	.13	.04	.11	.11	.10	.04	.12	.04	.04	.05	.05	. .	.04	. .	.05	. .	.01	.04	. .	. .
	1.5	.06	.05	.10	.12	.05	.10	.09	.09	.05	.09	.05	.04	.05	.06	. .	.03	.06	.06	.02	. .	.02	. .	. .
4	1.0	.28	.28	.30	.30	.18	.21	.22	.17	.19	.31	.15	.17	.17	.16	. .	.15	.11	.10	.05	.08	.09	. .	. .
	2.0	.19	.29	.29	.37	.12	.27	.25	.16	.17	.40	.08	.10	.17	.17	. .	.08	.10	.17	.05	.05	.04	. .	. .
	3.0	.18	.14	.27	.27	.16	.30	.30	.17	.17	.23	.15	.15	.16	.15	. .	.08	.13	.15	.10	.01	.01	.01	. .
6	1.0	.29	.41	.43	.42	.08	.30	.30	.16	.17	.40	.14	.16	.27	.20	. .	.10	.17	.21	.09	.04	.05	. .	. .
	2.5	.41	.43	.43	.55	.38	.37	.38	.25	.26	.55	.33	.34	.37	.29	. .	.26	.31	.38	.17	.09	.04	. .	. .
	4.0	.41	.41	.41	.55	.35	.50	.35	.23	.26	.46	.16	.18	.40	.28	. .	.14	.23	.37	.16	.07	.10	.12	. .

TABLE V—CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 4.08 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

Total head in feet.	Head-on-sprinkler, feet.	Number of Disk.																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	0.5	.05	.05	.04	.05	.05	.05	.05	.04	.05	.05	.04	.05	.05	.03	. .	.05	. .	. .	.02	.03	.03	.02	. .
	1.0	.08	.07	.07	.08	.05	.08	.11	.08	.08	.09	.04	.06	.09	.10	.04	.09	.08	.09	.05	.06	.05	.06	. .
	1.5	.08	.08	.05	.07	.05	.11	.09	.08	.08	. .	.05	.08	.09	.09	.06	.09	.09	.09	.05	.06	.06	.08	.04
4	1.0	.20	.17	.17	.18	.15	.22	.20	.17	.17	.22	.15	.19	.18	.16	.09	.18	.18	.15	.07	.16	.13	.13	. .
	2.0	.24	.25	.23	.31	.18	.35	.32	.19	.26	.30	.17	.21	.28	.27	.09	.20	.20	.27	.10	.15	.09	.18	.10
	3.0	.19	.17	.18	.25	.16	.26	.40	.18	.18	.31	.17	.20	.26	.31	.14	.18	.27	.20	.13	.12	.11	.17	.09
6	1.0	.30	.29	.25	.30	.24	.26	.24	.25	.26	.24	.23	.26	.27	.25	. .	.25	.26	.29	.25	.19	.17	.18	. .
	2.5	.26	.46	.38	.51	.38	.50	.60	.41	.40	.42	.33	.36	.57	.54	.20	.21	.35	.37	.27	.27	.22	.18	.11
	4.0	.36	.38	.28	.44	.31	.56	.62	.36	.42	.44	.26	.32	.46	.45	.25	.30	.30	.33	.35	.25	.18	.24	.14

TABLE VI — CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 8.47 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

Total head in feet.	Head-on-sprinkler, feet.	Number of Disk.																						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	0.5	.03	.03	.03	.05	.03	.05	.06	.04	.05	.05	.03	.04	.03	.04	.02	.04	.04	.04	.04	.04	.04	.03	.03
	1.0	.05	.05	.05	.07	.03	.07	.09	.05	.05	.07	.04	.05	.07	.07	.05	.07	.07	.06	.04	.05	.04	.05	.04
	1.5	.03	.06	.04	.05	.03	.09	.10	.05	.05	.08	.04	.04	.10	.10	.07	.07	.10	.08	.04	.05	.05	.06	.06
4	1.0	.10	.12	.11	.14	.09	.15	.14	.13	.14	.15	.12	.15	.15	.16	.09	.14	.16	.17	.09	.12	.11	.10	.09
	2.0	.12	.12	.11	.15	.09	.16	.18	.11	.13	. .	.10	.12	.20	.19	.11	.15	.18	.19	.12	.12	.10	.13	.09
	3.0	.11	.11	.10	.16	.09	.23	.24	.08	.09	. .	.10	.13	.23	.24	.13	.13	.20	.16	.09	.12	.10	.13	.09
6	1.0	.15	.15	.16	.17	.14	.18	.18	.16	.16	. .	.13	.17	.20	.19	.12	.15	.18	.18	.14	.15	.13	.13	.10
	2.5	.23	.23	.20	.23	.16	.24	.25	.21	.20	. .	.17	.20	.28	.30	.17	.20	.28	.30	.25	.20	.20	.22	.16
	4.0	. .	. .	. .	. .	.19	. .	.28	.18	.18	. .	.18	.22	.32	. .	.19	.30	. .	. .	. .	.18	.18	.18	.14

tables have therefore been corrected by referring the actual discharges to squares respectively 7.35, 11.3, and 16.3 feet on a side.

Taking up the independent variables tested in their order it is at once apparent that the efficiency of gravity distributors is markedly influenced by the rate of discharge on each disk, and that about 4 gallons a minute is the most favorable rate. The lower rate, 1.7 gallons per minute, gave very poor results with the larger disks, the liquid merely dripping over the edge. With the smaller disks fairly good results were obtained within a radius of 3 or 4 feet of the disk, although there was generally an excess of discharge nearest the centre. As the distance between sprinklers for this head was only 7.35 feet, the crude coefficients of .6 and .7 were not so greatly reduced as in other cases, and for the smallest (2-inch) disks this rate is better than either of the higher ones. Most of the 2-inch disks gave corrected coefficients of over .4 even with the 6-foot total head, and coefficients of over .5 were obtained for disks 4, 6, and 10.

The intermediate rate of 4.08 gallons per disk per minute did not suit the small, 2-inch disks as well as the lower rate, but with larger disks it gave better results. With good heads the liquid was well distributed, showing neither the concentration near the disk obtained with the lowest rate nor the marked outer ring characteristic of the higher one. Crude coefficients of over .7 were obtained with almost all the disks by using a 6-foot head, and the better ones ranged between .8 and .9. Furthermore, the wetted area was proportionately larger than with the higher or the lower rate of discharge; 4.08 gallons per disk per minute calls for a distance of 11.3 feet between sprinklers, and with high heads the better disks wetted circles 10 and 11 feet in diameter. The corrected coefficients remained, therefore, relatively high, several of the disks showing values over .5, and one, disk No. 7, over .6.

With the highest rate the better disks covered a 10-foot circle, but there was usually a ring of excessive discharge at a distance of 3 or 4 feet from the centre. The larger disks, at high heads, gave crude coefficients of between .7 and .8, wetting a circle of 6 feet radius. Corrected for a 16.3-foot square these crude coefficients are seriously reduced, only two of the corrected coefficients in Table VI being over .3.

The head used with the sprinkler disks was a most important factor in controlling their efficiency. The 2-foot total head proved inadequate in most cases. Some of the crude coefficients were fairly good (between .6 and .8); but the wetted area was always much too

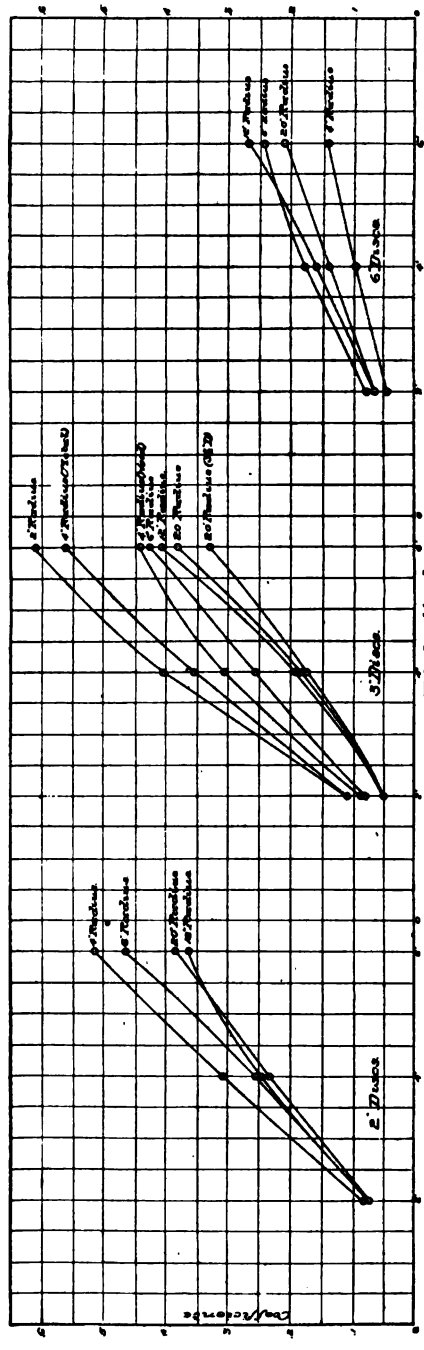

FIG. 10.—RELATION BETWEEN TOTAL HEADS AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE

Rate = 4.08 gallons per minute. Best head-on-sprinkler in each case.

small, giving an excessive rate near the sprinkler, and the corrected coefficients were almost always under .1. The 4-foot total head showed better results, and the 6-foot better still, the improved efficiency being directly proportional to the increase in head. This relation is indicated graphically in Figure 10 for the disks of 2, 3, and 6-inch diameters at the best rate of 4.08 gallons per disk per minute. The total heads are plotted as abscissæ and the best coefficients at the different total heads as ordinates. Each curve represents the results for one sprinkler disk, and the fifteen curves are arranged in three groups according to their diameters. The radius of curvature of each disk is indicated on the plot.

With regard to the best proportion of the total head to be used in the discharge above the disk, results are somewhat more variable. Increasing the head on the disk gives an enlargement of the wetted area, but it apparently brings about also an increased tendency to concentrated discharge in a single zone. The figures for the intermediate rate and 6-foot total head at the bottom of Table V include the best coefficients, and are fairly typical of the other results. They show that with a 6-foot total head a head-on-sprinkler of 2½ feet is most favorable for the shallower sprinklers, and a value of 4 feet is better for the deeper ones. The 1-foot head-on-sprinkler is always inadequate to secure a proper splashing discharge. These results are indicated with greater clearness in Figure 11, where the coefficients for the best rate (4.08 gallons per minute) and best total head (6 feet) are plotted for the three values of head-on-sprinkler which were tested. The curves on the diagram otherwise correspond to those of Figure 10. The dimensions of each disk are indicated in Figure 9.

There remains still to be considered the influence of the shape of the splashing disk itself. Two general patterns were studied — simple concave plates and disks of the "mushroom type" with a raised central cone (Nos. 13, 14, 17, 18, and 19). The latter show coefficients intermediate between the large and small concave disks, better than the former and not so good as the latter. In other words, the slope on one side of the central boss deflects the water very much as a simple cup of similar size and curvature would do. The discharge from these disks was, however, unequal along different radii, since it was almost impossible to make the stream of liquid strike the central boss. The coefficients are therefore higher than they should be, since the revolving trough caught portions of unequal discharges in

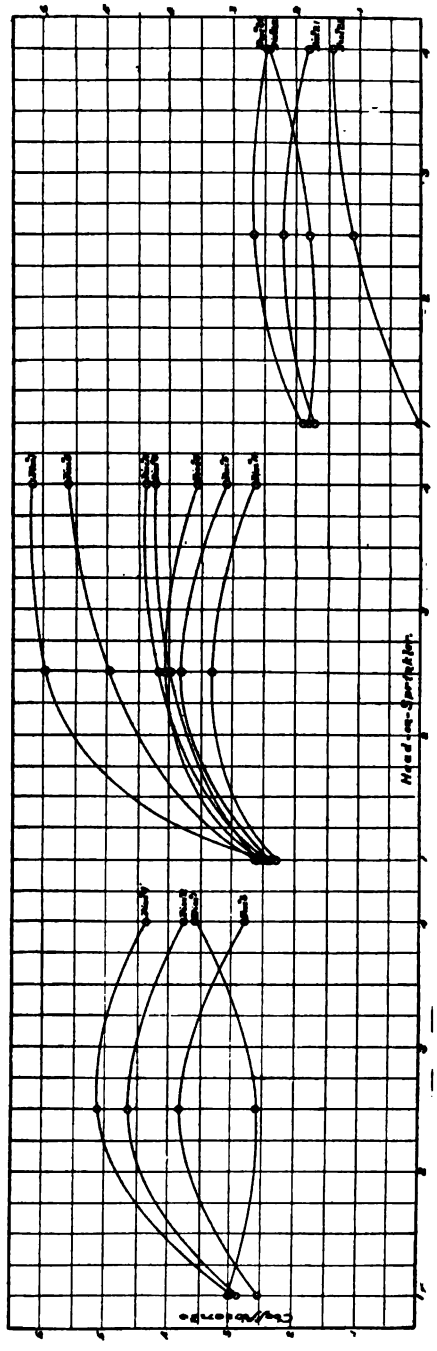

FIG. 11.—RELATION BETWEEN HEAD-ON-SPRINKLER AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE
Rate = 4.08 gallons per minute. Total head = 6 feet.

different zones along the various radii. There seems to be no advantage in the use of disks of this pattern.

There remain the simple concave plates, varying in diameter and in radius of curvature. For diameter, 3 inches is clearly the most favorable size. A comparison of the three sets of curves in Figure 10 shows that the 3-inch disks (Nos. 5, 6, 7, 8, 9, and 10) are better than the 2-inch disks (Nos. 1, 2, 3, and 4), and far superior to the larger ones (Nos. 20, 21, 22, and 23). These figures, it must be remembered, relate to the 4.08-gallon discharge. At the lower rate (1.71 gallons per disk per minute) the 2-inch disks give higher coefficients than the 3-inch ones. This might be expected, since poor distribution with large disks arises from the fact that the liquid has not force enough to splash freely off, but pools and drips over the edge. The smallest disks are therefore best suited to low discharges, but the 3-inch disks and 4.08-gallon rate form the best combination.

The effect of varying radius of curvature is well shown in Figure 10 for the 4.08-gallon rate; and the constancy of the relation is indicated by the comparison made in Table VII.

TABLE VII — ORDER OF DISKS ACCORDING TO THEIR COEFFICIENTS (BEST DISK FIRST)

Rate, gallons per minute per disk.	Total head.	Diameter of Disks.		
		2 inches.	3 inches.	6 inches.
		Radii.	Radii.	Radii.
	Feet.	Inches.	Inches.	Inches.
1.71	2	4 6 12 20	2 4 4 12 6 20 20	20 12 6 4
	4	4 20 6 12	4 2 4 6 12 20 20	20 12 6 4
	6	4 6 20 12	2 4 12 6 20 20	6 12 20 4
4.08	2	4 6 12 20	2 4 4 12 6 20 20	6 20 12 4
	4	4 6 12 20	2 4 4 6 12 20 20	6 12 20 4
	6	4 6 20 12	2 4 6 12 20 20	12 6 20 4
8.47	2	4 6 12 20	2 4 4 6 12 20 20	6 4 12 20
	4	4 6 12 20	2 4 4 6 12 20 20	6 12 20 4
	6	4 6 12 20	4 2 6 20 20 12	6 12 20 4

Efficiency evidently increases with the increasing concavity of the disks. Disks Nos. 12 and 16, with very flat surfaces, gave such poor

results that they have not been plotted. The improvement with increase in curvature is most marked with the disks of small diameter, and with the 6-inch disks the 12-inch radius of curvature is the maximum, the 4-inch radius giving very poor results. This is brought out more clearly in Figure 12, where the coefficients at the 4-foot head are plotted against the actual depth of the disks of various diameters. An increase in concavity increases the efficiency of the disk by breaking the liquid up more completely and sending it higher into the air. The accompanying increase of disk surface over which the liquid must travel tends, however, to decrease the efficiency of distribution, probably by

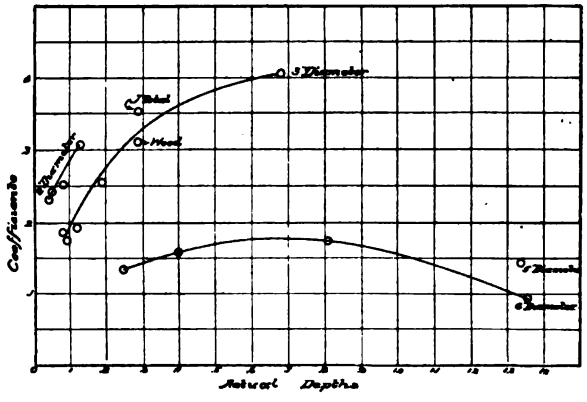

FIG. 12.—RELATION BETWEEN DEPTHS AND COEFFICIENTS FOR DISKS OF DIFFERENT DIAMETERS

Rate = 4.08 gallons per minute. Total head = 4 feet. Best head-on-sprinkler in each case

the greater friction involved. With small disks this is not serious, but as the surface is increased this factor limits the possible increase in concavity. Disk No. 15, with a diameter of 5 inches and a radius of curvature of 3 inches, represents an extreme condition in which the liquid did not splash at all, but eddied about in the deep cup and merely dripped over the edge.

The only other point noted was the effect of the composition of the disks. Nos. 6, 7, and 15 were of metal, spun out of No. 18 sheet copper. All the others were of white pine, turned and carefully smoothed on the lathe, and varnished. No. 15, as noted above, was of very poor shape, but Nos. 6 and 7 gave the best results obtained in the whole series. No. 7 had a 2-inch radius of curvature, and should therefore have given better results than the others, which were of less

concavity. No. 6, however, was of the same size and shape as No. 10 (of wood). Its coefficients were distinctly better under the most favorable heads. Thus at the 4.08-gallon rate, with a 6-foot total head and 2.5-foot head-on-sprinkler, No. 6 gave .49 against .42 for No. 10; with 4-foot head-on-sprinkler it gave .56 against .44.

In general, it appears from this portion of the investigation that the best results with gravity distribution can be obtained under the following conditions:

1. The discharge on each sprinkler should be in the neighborhood of 4 gallons per minute; this means, for a 2,000,000-gallon rate, 340 sprinklers per acre, with a distance between the sprinklers of about 11 feet.

2. The head between the distributing trough and the filter should be as great as possible; 2 feet is inadequate, 4 feet gives fair results, and 6 feet is better. Where exceptional conditions make still higher heads possible, the use of large, deep disks might prove of advantage.

3. The head on the sprinkler should be from 2 to 4 feet. The best subdivision of available total head can probably best be determined by experiments with the disks to be used in each individual case.

4. A simple concave disk of metal seems to promise the best efficiency.

5. The best diameter for the disks appears to be 3 inches. For low rates of discharge smaller disks are better, and for very high rates or very high heads larger ones may be more suitable.

6. Unless the disk be too large it is of advantage to increase its concavity as much as possible. Of 3-inch disks, that having a curvature corresponding to a radius of 2 inches proved most satisfactory. The radius of curvature might profitably be increased toward the limiting value of 1½ inches, which would make the disk a hemisphere. With larger disks larger radii of curvature are necessary.

Of all the disks studied, the best was No. 7, a metal cup, 3 inches in diameter, with a radius of curvature of 2 inches. With a total head of 4 feet and a head-on-sprinkler of 3 feet, it gave a coefficient of .40, the best obtained with that total head; and with a total head of 6 feet and a head-on-sprinkler of 4 feet, it gave the highest coefficient obtained for any gravity distributor, namely, .62.

V. Determination of Coefficients for Pressure Distributors

The system of spraying sewage upward from fixed sprinkler nozzles under pressure was developed more or less independently at various plants in England. At Salford it was worked out after the failure of various other methods, in which the sewage overflowed from troughs, or was spread by a thin layer of sand covering the filter proper. In the earlier experiments with fixed nozzles, a disk-like cap was placed a little above each in order to break the sewage into a fine spray. Then the attempt was made to break up the stream by the impact of two converging flows; and finally a nozzle was designed which discharged the sewage from a series of openings arranged spirally about a centre. In Derbyshire, Barwise describes as common the use of fixed perforated pipes with metal disks placed over the outlet to form a spray (very much like the earliest Salford type). At Birmingham small sprinkler heads are used, in which the sewage passes up through a narrow, annular opening and is broken up and thrown outward by striking the bottom of a metal plug raised a little above it.

In America the first tests of trickling filter distribution were made at Columbus, Ohio. For the preliminary experiments of 1904–05 a nozzle was designed which recalls that used at Salford. The sewage was discharged through eight ⅛-inch brass pipes, at an angle of 45° with the vertical, into the space between an inner and an outer cone. The sewage left the nozzle in a tangential direction and spread in a fine sheet. Clogging proved too serious an objection to this nozzle, and another design was finally adopted. The latter was described by Mr. J. H. Gregory in the *Transactions of the American Society of Civil Engineers*, 57, 130, as follows: "The nozzle, which is of brass, consists of a single orifice, $\frac{9}{16}$ inch in diameter, with rounded edges, above which, held by two thin arms, is an inverted 90° cone, the axis of the cone coinciding with the axis of the orifice. The jet, on leaving the orifice, impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops. At the points where the sheet strikes the arms the latter are ground down to sharp edges on each side, thereby permitting the sheet to heal up entirely after passing them."

At the Waterbury Experiment Station, Mr. W. G. Taylor has made a careful study of the general operation of sprinkler nozzles, and has devised still another type. He reports (*Engineering Record*, 55, 10)

that a single opening with a cone above for distribution, supported at the sides as in the Columbus nozzle, proved unsatisfactory. The side supports broke the sheet badly, especially after the development upon them of a fungous growth. Furthermore, he points out that the "uniformity of distribution obtained by means of a single cone acting under a head of 5 feet was not satisfactory. Although the efficiency as marked by the area wetted was approximately 75 per cent., a certain outer zone invariably received sewage at a higher rate than the inner area. To lessen this defect, and to secure a greater percentage of wetted area and a more uniform distribution of the sewage, the idea occurred to the writer of placing a lower and secondary cone over the orifice, with the object of intercepting a portion of the sewage and distributing it over the inner fifth of the circular area within the range of the nozzle. The result was effected by boring a hole through the lower cone slightly less in diameter than the fixed orifice in the nozzle, the diameter of the opening in the cone being so proportioned to the diameter of the nozzle orifice that four-fifths of the rising stream passes through the lower cone to be diffused by the upper, and the remaining fifth is sheared off by the lower cone and sprinkled over the central area."

It is evidently desirable to have an accurate measure of the comparative performance of these sprinkler nozzles and of the still better designs which the future will probably develop. Mr. Gregory, in describing the Columbus experiments, was content to say that the nozzle used wetted 77 per cent. of the tributary area "in a perfectly satisfactory manner." Mr. Taylor noted, but did not measure, serious inequalities of distribution within the wetted area. We were therefore particularly glad to apply our method of measuring efficiency to the most promising of these pressure nozzles, and the results have proved significant. Through the kindness of Mr. G. C. Whipple, of New York, we have been furnished with two of the nozzles used at Salford and with the Birmingham type. To Mr. Gregory we owe the Columbus sprinkler, and Mr. Taylor has courteously given us drawings of the Waterbury design. The tests of these five types may best be discussed one by one, and reviewed in comparison with each other later.

The Salford nozzle (old style) is a brass nozzle in the form of a cup, with two openings in the sides at such an angle that the streams discharged upward from them meet in the cup itself. Its construction is shown in Figure 13.

This nozzle differed from all others tested in the fact that it did not discharge equally along different radii. It threw the liquid up in a fan-shaped spray, in quite a narrow plane, as indicated in Figure 14. Our ordinary method of rating efficiency, which assumes symmetrical distribution about the centre, was of course inapplicable under such circumstances. Instead, therefore, of revolving the measuring tank about this sprinkler, we measured the discharge at six different station-

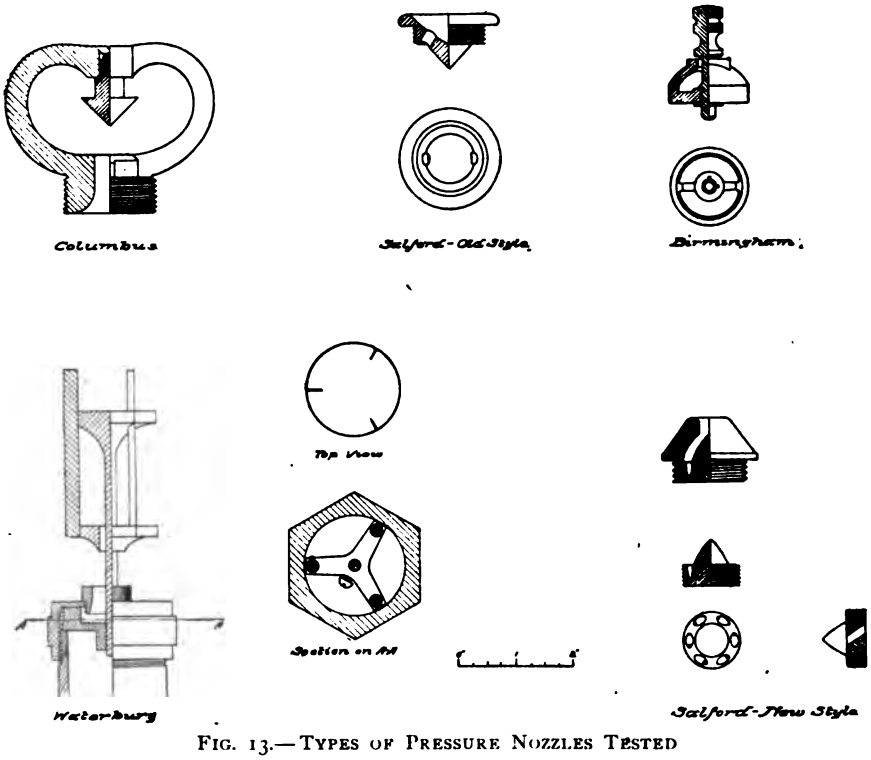

FIG. 13.—TYPES OF PRESSURE NOZZLES TESTED

ary positions, immediately adjacent to each other and together covering one-half of the entire circle surrounding the distributor. The average discharge in each zone was used in the manner described above for calculating the crude coefficient. Then the mean discharge along each sector was determined, and from this the total excessive discharge along those sectors which received more than their share. The ratio of the excessive radial discharge to the total discharge was then determined and taken from unity, giving the "radial coefficient." The

product of the crude coefficient and the radial coefficient measures the evenness of distribution within the wetted area.

When this sprinkler nozzle was tested under a head of 6.4 feet, another anomaly appeared in connection with the determination of the corrected coefficient. The area wetted was larger than the square which would be tributary to each sprinkler at a 2,000,000-gallon rate.

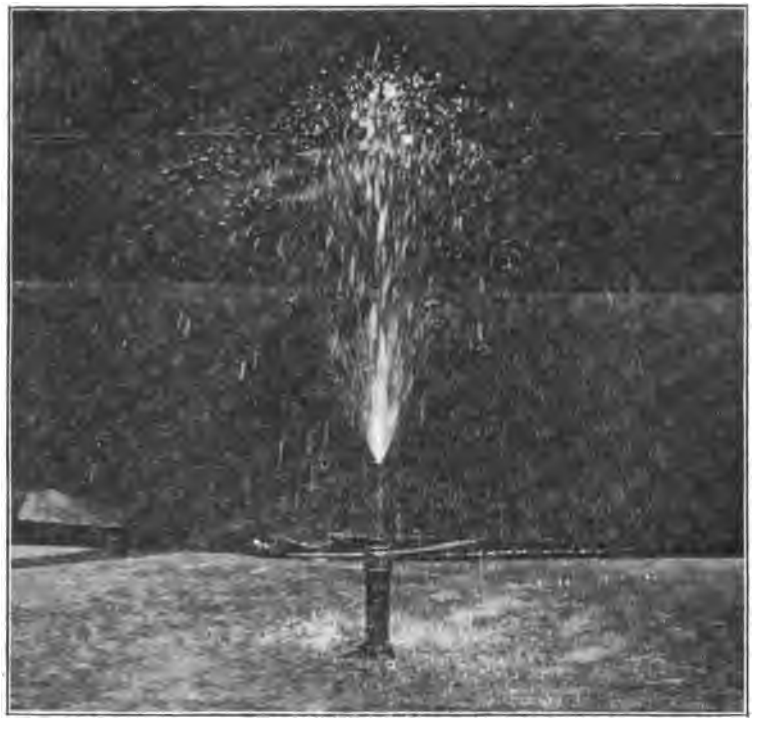

FIG. 14.—VIEW OF SALFORD OLD STYLE NOZZLE IN OPERATION

This means, of course, that at this head and rate the circles would overlap. The following method of calculation was applied in this case and in others of the same kind.

The effect of overlapping circles of spray is exactly the same as it would be if each portion of the spray passing the boundary of the tributary square were perfectly reflected at the side of that square and returned to a corresponding point within. It is necessary, therefore, to calculate how much of the discharge into the outer rings would have been thus reflected, or, in other words, what proportion

of each of the overlapping rings falls without the square. Given the dimensions of the square and of each ring, this is a simple problem in trigonometry, the solution of which gives,

$$\frac{P}{100} = \frac{\cos^{-1}\frac{S}{D}}{45^\circ},$$

in which S is the side of the square and P the percentage of the total discharge into any overlapping ring of diameter D, which would be reflected to an inner ring. Having subtracted from all the rings the amounts which would be reflected, it is next necessary to distribute these amounts among the inner rings where they properly belong. The mathematical solution of this problem gave a result too cumbrous to use. A graphical representation of the conditions drawn on plotting paper, however, indicated readily and with sufficient accuracy the amounts of the reflected discharge which would fall into each of the inner rings affected, and the reflected water was then redistributed. These new values were then recalculated like the others and a coefficient obtained, which referred, not to a circle, but to the area common to the maximum circle and the intersecting square. The relation between this area and that of the square furnished the required factor for the calculation of the corrected coefficient from the crude.

The results of the tests on the Salford old style nozzle are shown in Table VIII. The total head, in this and succeeding tables, is the difference in level between the surface of the liquid in the supply box and the top of the measuring tank. The head-on-sprinkler is the difference in level between the surface of the liquid and the nozzle itself. In general, the nozzle was placed as close as possible to the top of the tank.

One very interesting point about this nozzle is brought out in the column of rates. The discharge with a head-on-sprinkler of 6.2 feet was less than with a head-on-sprinkler of 3.9 feet. This is apparently due to the fact that the two converging streams discharged by this nozzle meet in its cup with such force as to produce a back pressure, which at high heads cuts down the flow appreciably.

TABLE VIII — COEFFICIENTS FOR SALFORD OLD STYLE PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Coefficients.			
			Crude.	Radial.	Product.	Corrected.
Feet.	Feet.					
2.0	1.9	2.6	.65	.56	.36	.08
4.1	3.9	3.8	.73	.53	.38	.16
6.4	6.2	2.9	.76	.58	.44	.41

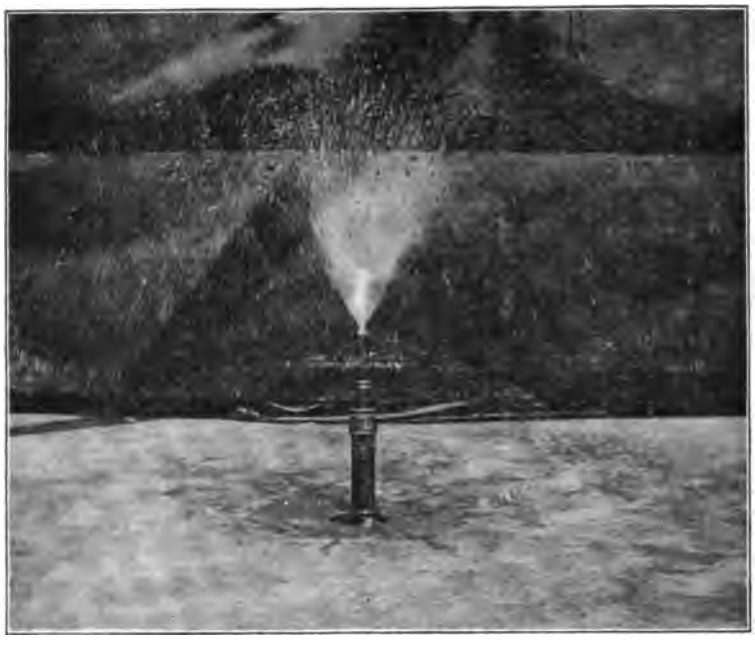

FIG. 15.— VIEW OF SALFORD NEW STYLE NOZZLE IN OPERATION

It is evident from the column of crude coefficients that this nozzle secures a fairly even distribution within the wetted sector, improving with the head to a very high value. There is an area of excessive discharge near the outer limit of the wetted sector, but the excess is not great. The inequality of distribution along different radii is much more serious. Nearly half the liquid is discharged in excess on one of the six 30° sectors, and this weakness causes the products and corrected coefficients to be poor.

The Salford new style sprinkler tested is a double cone, the outer cone being open at the top. The liquid enters the space between the

cones through six holes of $\frac{5}{32}$ inch diameter, inclined at an angle to the major axis, so that a spiral motion is produced within the inner cone. This sprinkler is shown in Figure 13, and its general method of operation is indicated by the photograph reproduced in Figure 15.

With this, as with the other pressure nozzles, distribution along different radii was approximately equal, and tests were made in the manner described in Section II by revolving the measuring tank about the distributor. Duplicate determinations were made at each of the three heads tested, and the results are shown in Table IX. As in the case of the old Salford nozzle, at high heads a wetted area was obtained extending beyond the sides of the calculated tributary square, and the factor was therefore corrected by the method described above (page 359). The crude coefficients refer in all cases to the actual wetted circles.

TABLE IX — COEFFICIENTS FOR SALFORD NEW STYLE PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	2.2	0.7	.37	.22
2.2	2.2	1.2	.44	.16
4.3	3.8	1.6	.68	.39
4.3	3.8	1.7	.70	.38
6.4	6.1	2.0	.78	.67
6.4	6.1	2.1	.77	.65

The results of these tests indicate that the new Salford sprinkler gives very good results at the higher heads. The tests themselves show an excessive discharge on the outer part of the wetted area, but the excess is small, giving crude coefficients of .6 and .7 at 3.8-foot and 6.1-foot heads. At the 3.8-foot head, however, the wetted area (a circle of 3 feet radius) is small in proportion to the rate. The corrected coefficient is therefore poor, while that obtained at the 6.1-foot head, with only slightly higher rate and a circle of 4 feet, remains in the neighborhood of .7.

The Birmingham nozzle, shown also in Figure 13, discharges through a ⅜-inch opening. Through this opening passes a $\frac{7}{32}$-inch shank, the enlarged upper portion of which breaks up the ascending ring of liquid and sends it out in a fine spray. The working of the nozzle is shown in Figure 16, and its results are indicated in Table X. In

this case the discharge through the opening was so small and the distribution so good that a circle larger than the proper tributary square

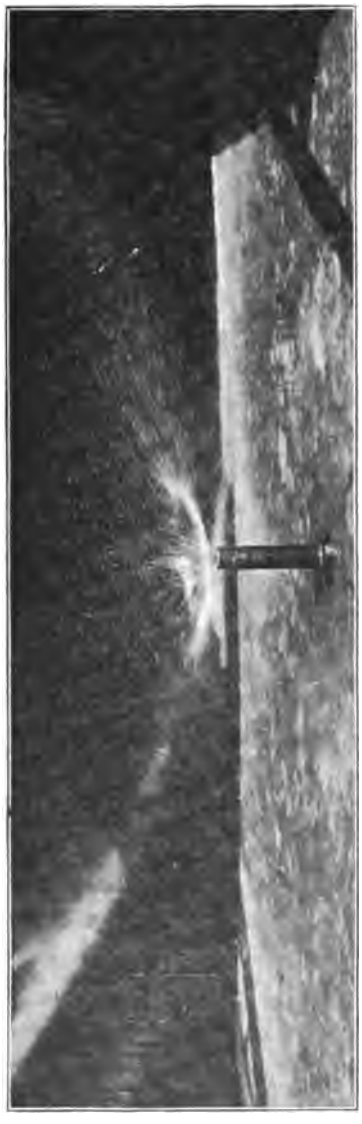

FIG. 16.—VIEW OF BIRMINGHAM NOZZLE IN OPERATION

was wetted in every test except those made at the 2.2-foot head. The results are therefore corrected, as in the cases above.

TABLE X — COEFFICIENTS FOR BIRMINGHAM PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	2.0	0.9	.58	.44
2.2	2.0	1.0	.62	.38
4.3	4.1	1.4	.80	.80
4.3	4.1	1.5	.76	.72
6.4	5.8	1.8	.84	.69
6.4	5.8	2.0	.78	.66

These figures are of the greatest interest as showing what results may be obtained with a nozzle of small bore so arranged as to break up the stream quickly and completely. With a low rate of discharge, due, of course, to the obstructive construction of the orifice, a relatively large circle was covered (of 2.5 feet radius at the 2-foot head, 4 feet radius at the 4.1-foot head, and 5 feet radius at the 5.8-foot head); and within this circle the distribution was remarkably even. With this nozzle the 4-foot head proved better than the higher one, since at the 5.8-foot head a more definite ring of excessive discharge was formed. Under the best conditions this nozzle gave corrected coefficients of .7 to .8. It is clear that the Birmingham nozzle effects a far more perfect distribution than any other device we have examined.

The Columbus nozzle is designed on a plan exactly opposite to that of the Birmingham sprinkler, in so far as it aims to enlarge the orifice of discharge as much as possible. The Columbus design has been described above, and is also shown in Figure 13. Figure 17 illustrates its method of operation.

TABLE XI — COEFFICIENTS FOR COLUMBUS PRESSURE DISTRIBUTOR

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.			
2.2	2.2	7.1	.54	.12
2.2	2.2	7.1	.60	.14
4.3	4.3	10.9	.63	.21
4.3	4.3	10.9	.65	.22
6.4	6.4	14.8	.61	.30
6.4	6.4	15.8	.62	.26

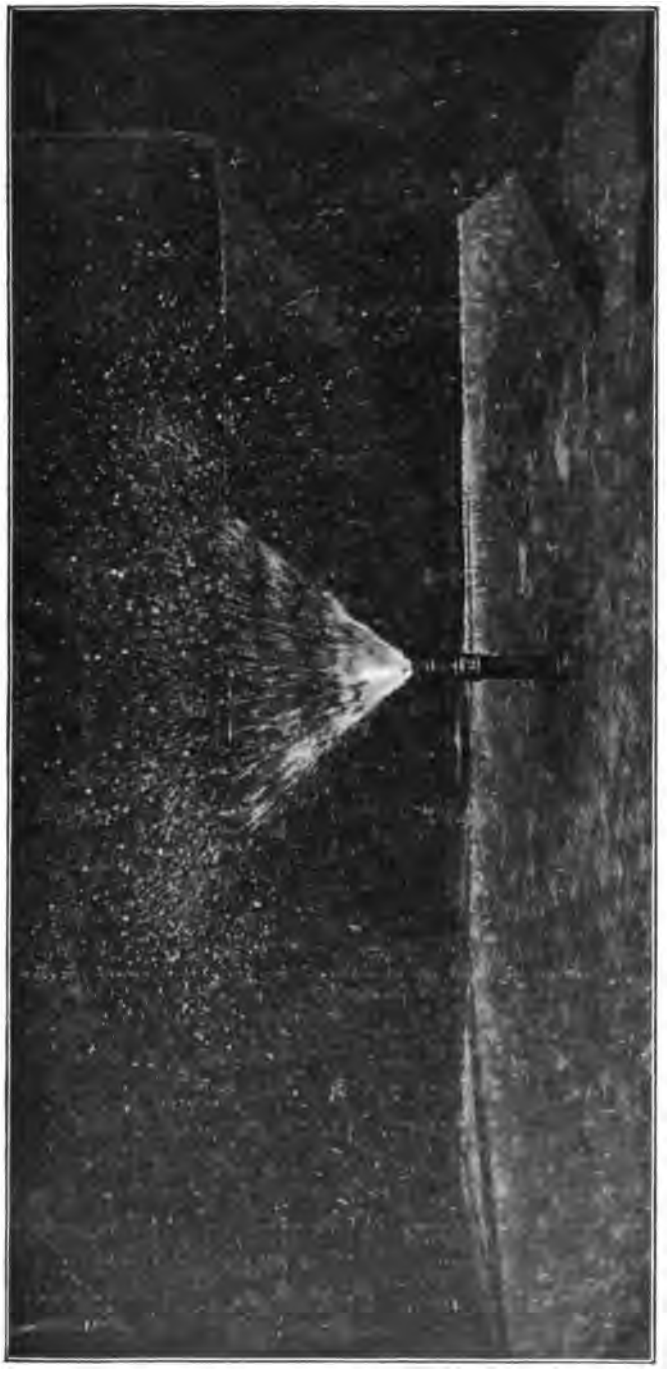

FIG. 17.—VIEW OF COLUMBUS NOZZLE IN OPERATION

The Columbus sprinkler shows at all heads a fair distribution within the wetted area, its departure from the ideal condition being due to the formation of a zone of excessive discharge a little inside the periphery of the wetted area. Crude coefficients, however, are always about .6, and one notable thing about this nozzle is the fact that it gives fairly even distribution even at the 2-foot head. The wetted area is, however, small in proportion to the discharge, and therefore the corrected coefficients are poor. Thus at the 4.3-foot head, for example, the rate of discharge of the nozzle was 10.9 gallons per minute. This discharge, if the total rate on the filter be 2,000,000 gallons per acre, calls for 121 sprinklers per acre, which means a distance of 19 feet between sprinklers. The wetted circle at this head was only 6 feet in radius, so that at an ostensible 2,000,000-gallon rate half the filter area would be working at 4,000,000 gallons and the rest would be idle. It is no doubt for this reason that the Columbus engineers plan to operate at a 4,000,000-gallon rate for half the time, and to rest the whole filter the remainder of the time, spacing their nozzles 16.2 feet apart. This would of course give a distribution more nearly approaching our crude coefficients, though the results at best would be below .6.

The Waterbury nozzle used in these experiments was of the type described on a preceding page (356), in the citation from Mr. Taylor's paper. Its construction is indicated in Figure 13. Briefly the nozzle consists of two cones, one above the other, the lower one perforated at its centre. An annular discharge is in part deflected outward by the lower cone, while its inner portion passes through the lower cone and is deflected by the upper one. As shown in Figure 18, the result is to produce two concentric cones of spray and thus improve the distribution obtained with a nozzle of the Columbus type. In the sprinkler tested by us, the position of each cone in relation to the point at which the liquid leaves the pipe below could be varied by means of set screws, and a number of different settings of these cones were examined. The distance between the lower opening and the lower surface of the lower cone at its outer rim is designated by the letter a; the distance between the upper surface of the lower cone and the lower surface of the upper cone is designated by the letter b. Reference to Figure 13 will make the significance of these dimensions clear.

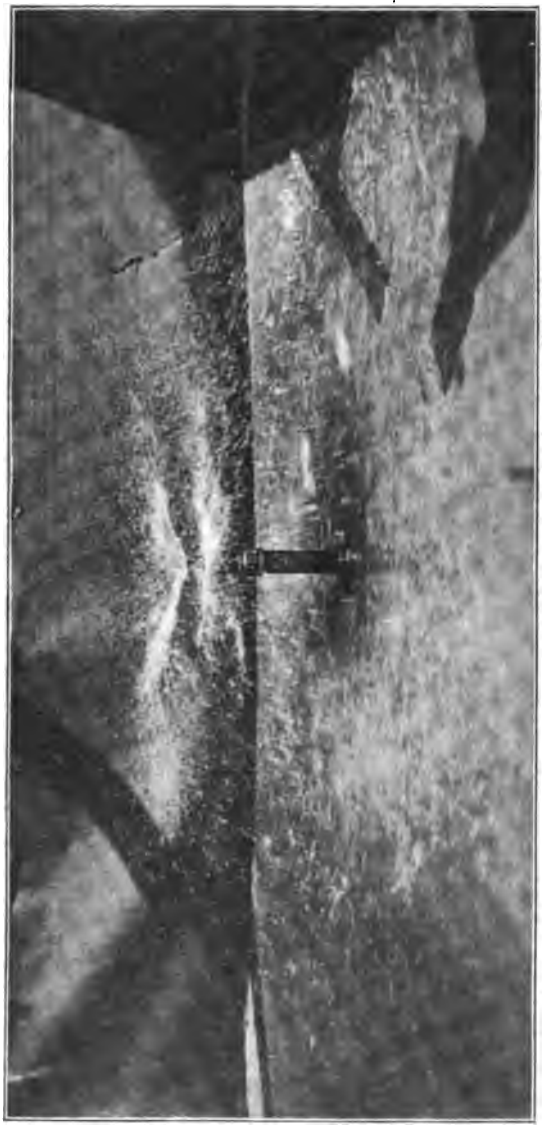

FIG. 18.—VIEW OF WATERBURY PERCONATE NOZZLE IN OPERATION

TABLE XII — COEFFICIENTS FOR WATERBURY PRESSURE DISTRIBUTORS

Total head.	Head-on-sprinkler.	Rate, gallons per minute.	Height of Cones.		Crude coefficient.	Corrected coefficient.
			a.	*b.*		
Feet.	Feet.		Inches.	Inches.		
2.2	2.2	5.4	1⅜	1¾	.46	.05
2.2	2.2	5.6	1⅜	1¾	.45	.05
4.3	4.3	7.6	¾	1¾	.53	.11
4.3	4.3	7.8	¾	1¾	.62	.13
4.3	4.3	7.5	1⅜	1⅛	.62	.13
4.3	4.3	7.7	1⅜	1⅛	.62	.14
4.3	4.3	7.6	1⅜	1¾	.62	.14
4.3	4.3	7.7	1⅜	1¾	.68	.14
4.3	4.3	7.8	1⅜	1¾	.66	.13
6.4	6.3	6.8	¾	1¾	.68	.21
6.4	6.3	10.2	¾	1¾	.72	.21
6.4	6.2	8.6	1⅜	1⅛	.62	.15
6.4	6.4	9.6	1⅜	1⅝	.69	.22
6.4	6.4	10.4	1⅜	1⅝	.73	.22
6.4	6.2	9.3	1⅜	1¾	.77	.21

The results of the tests on the Waterbury sprinkler are indicated in Table XII. It will be noticed that the rates varied somewhat under the same conditions. This was no doubt due to the tendency of this sprinkler to clog. Our tests were all made with water, but the tanks through which it was pumped were not perfectly clean and at times contributed their quota of suspended solids (old sewage sludge). These inequalities did not, however, seriously affect the coefficients, which are fairly uniform. It appears from this table that the relative position of the cones does not greatly modify the efficiency of distribution, although there is a slight but distinct improvement in coefficients with an increase in the value of *b*. That is, an increase in the distance between the upper and lower cone improves distribution by throwing the outer cone of liquid further out and separating it more distinctly from the inner one.

In all cases, however, there is more or less fusion of the two cones of spray, and our tests showed a single zone of excessive discharge, not near the periphery of the wetted area, as with the Columbus nozzle, but about a third or a half of the way out from the centre of the wetted circle. The crude coefficients at 4.3-foot and 6.4-foot heads were a little higher than those obtained with the Columbus nozzle, averaging

a little over .6 for the lower and about .7 for the higher head. The wetted area with this nozzle is, however, small for its high rate of discharge. The largest circles wetted were 11 feet in diameter, and this was at rates of about 10 gallons per minute, corresponding to distances of 18 feet between sprinklers. The corrected coefficients are therefore low, the best of them being barely over .2.

Mr. Taylor has worked out certain modifications of his sprinkler which have not been examined in the present investigation, but which well deserve a careful study. Two of these are described in the paper previously cited (*Engineering Record*, **55**, 10) and more fully in a somewhat later one (*Engineering News*, **57**, 238). One consists of a six-winged revolving cone supported directly over a single orifice, through which the sewage rises. The six blades, shaped like air blowers, are rotated by the force of the liquid striking them, and their curvature gives the drops of sewage, leaving them a widely varying angle of elevation. A still more interesting nozzle has a cone similar to that tested in our experiments, but with a vertical cut in each quadrant of the cone. The upper surface of the conical piece has almost the shape of a four-leaf clover, though not cut in so deeply, and the sewage is discharged from the outer rounded corners at a more oblique angle than from the incised areas between. It is hoped that by the proper construction of a cone of this type "the sewage film when leaving shall have such varying angles of elevation that it shall, upon diffusion, throw the proper proportion of drops the distance required to cover the side of the square, while midway between these points, on the diagonal lines, the drops will, by reason of their greater angle of elevation, be thrown with the tendency to fill the corners of the square."

VI. The Efficiency of Pressure Distributors with Varying Heads

With a sprinkler which, like many pressure nozzles, discharges in a conical sheet and forms an excessive discharge on a peripheral zone, it would seem to be of advantage to vary the head-on-sprinkler in such a way as to cause the zone of excessive discharge to travel in and out over the wetted area. This may easily be done by the interposition of siphon tanks in the supply system, and such is the practice at many of the English plants, notably in Derbyshire (Barwise, "Purification of Sewage," London, 1904). The Board of Advisory Engineers to the

Baltimore Sewerage Commission have suggested a similar arrangement for their projected trickling filters (Report of the Board of Advisory Engineers and of the Chief Engineer, Baltimore, 1906). At Columbus, Mr. Gregory, in the paper previously cited (*Transactions of the American Society of Civil Engineers*, **57**, 130), states that the sprinklers will be operated at a head varying during twenty-four hour periods from 2.75 feet (a rate of 10 gallons per minute per sprinkler) to 5 feet (a rate of 13.5 gallons). We have had a Columbus nozzle with varying head in operation on the trickling filter at the Technology Experiment Station since the summer of 1906 with apparently good results, and the Massachusetts State Board of Health has used a siphon tank in connection with their gravity distributor at Andover (*Engineering News*, **57**, 397).

It is clear that such varying heads must tend to improve the efficiency of devices like the Columbus sprinkler. Just how much improvement is effected under such conditions can, however, only be determined by exact measurement. We have therefore made a study of the operation of the Columbus sprinkler at varying heads, and the results have proved of considerable interest.

We used in our series of tests a maximum head of 4 feet (in two cases 3.7 feet) and a varying minimum head from 3.5 down to 2 feet. The discharge was made from a square siphon tank equipped with float valves so as to start and cut off sharply. The time of filling this tank varied from thirty-seven seconds to three minutes and forty-eight seconds, and the time of its discharge from twenty-seven seconds to two minutes and forty-seven seconds.

The rate in all cases was in the neighborhood of 4 gallons per minute. It was somewhat higher than this in some tests, but the wetted area was in all cases a circle of 10 to 10.5 feet diameter, and the rates corresponded with sufficient closeness to a spacing of nozzles 11 feet apart, on which basis all have been calculated. The coefficients are therefore comparable with those given for a constant head of 4.3 feet in Table XI. These results are reproduced for comparison in Table XIII.

TABLE XIII—COEFFICIENTS FOR COLUMBUS DISTRIBUTOR WITH VARYING HEAD

Maximum head.	Minimum head.	Crude coefficient.	Corrected coefficient.
Feet.	Feet.		
4.3	4.3	.63	.21
4.3	4.3	.65	.22
4.0	2.0	.45	.30
4.0	2.5	.50	.33
4.0	3.0	.56	.37
4.0	3.0	.56	.37
4.0	3.2	.53	.41
4.0	3.5	.53	.41
4.0	3.5	.55	.43
3.7	3.5	.49	.32
3.7	3.5	.48	.38

It was expected, *a priori*, that a varying head would give more even distribution within the wetted area; and to the eye the waxing and waning cone of spray looks well-nigh perfect. Nothing could better illustrate the importance of the rigorous method of measurement adopted in these experiments. The crude coefficients in Table XIII are distinctly poorer with varying than with constant heads. An inspection of the original measurements shows the presence of a well-marked zone of excessive discharge just as in the case of the constant head, only not so far out from the centre of the wetted area. A large excess of the liquid was found in the compartments 2 and 2½ feet out from the nozzle. The smaller radial distance of this maximum zone accounts for its greater effect in reducing the coefficient.

On the other hand, the corrected coefficients were much improved by the intermittent operation. The wetted area was as great as in the tests at a constant head of 4 feet and the discharge was much less. The average rate was as low as 4 gallons per minute per sprinkler. Therefore, for a total rate of 2,000,000 gallons per acre the nozzles could be placed much closer than at a 4-foot constant head (11 feet instead of 19), and the wetted area made to approximate more nearly to the tributary squares. Thus the corrected coefficients for a head varying from 4 feet down range from .3 to .4 against a little over .2 for the constant head of 4.3 feet.

With regard to the best construction for a siphon tank, Table XIII brings out several suggestive points. Taking the maximum heads of

4 feet, it is apparent that the evenness of distribution within the wetted area is better when the tank is not too long in emptying, since the crude coefficients are better with a minimum head of 3 feet and over than with lesser ones. As the minimum head is increased, the corrected coefficient rises still more rapidly, increasing progressively from .30 to .43. This is because the wetted area at 3.2 feet and 3.5 feet minimum heads was somewhat larger than with a lower minimum, while the evenness of distribution was as good as at a 3-foot minimum head. Evidently the best siphon tank is one with a short range of level which will discharge a small volume of sewage at frequent intervals. In our tests the best arrangement was such that the tank filled and emptied in about one minute, the change of head being from 4 feet to 3.5 feet. The decreased maximum head in the last two lines of the table shows an injurious effect on both crude and corrected rates.

The siphon tank used in these experiments was a simple box of square section, but Mr. Taylor (*Engineering Record*, **55**, 10) has suggested a design which promises better results. He points out that on theoretical grounds a nozzle acting under a straight-line variation of head from maximum to minimum, such as that produced by the discharge of an ordinary tank under siphon action, could not lead to perfect results. To produce ideal distribution the head upon the nozzle should vary less rapidly near the maximum point than near the minimum. He found that the rate of the desirable variation was represented by a parabolic line.

VII. Comparative Efficiency of Distributors of Various Types

The optimum conditions for distributors of various types have been somewhat fully discussed, but a brief comparative summary of their performance may be of interest in closing. We have therefore summarized the results under optimum conditions (4-foot total head for Birmingham, 6-foot for the others) in Table XIV.

TABLE XIV—COMPARATIVE EFFICIENCY OF DISTRIBUTORS OF VARIOUS TYPES

Type.	Rate, gallons per minute.	Crude coefficient.	Corrected coefficient.	Sprinklers per acre to discharge 2,000,000 gallons per day.
Best gravity distributor	4.08	.76	.62	341
Old Salford	2.9	.44	.41	483
New Salford	2.1	.78	.67	667
Birmingham	2.0	.80	.80	700
Columbus	14.8	.61	.30	94
Waterbury	10.4	.73	.22	134

The American pressure nozzles, judged on the basis of these measurements, show a low efficiency in distribution. They cover the wetted area fairly well under the best conditions, but their discharge is so excessive that at a total rate of 2,000,000 gallons per acre they leave large waste areas between, and their corrected coefficients are correspondingly low. It must, of course, be remembered that at a rate of 4,000,000 gallons per acre, for which the Columbus nozzle at least is designed, the corrected coefficients would be much higher. Furthermore, the performance of these nozzles may be further improved by the use of varying head, which increases a coefficient of .2 (for 4-foot total head) to .4 (for a head varying between 3.5 feet and 4 feet). This question of varying heads well deserves further study, especially in the light of Mr. Taylor's plan for parabolic variations. The Columbus nozzle offers great advantages in the simplicity of its construction and in its large orifice if its excessive discharge can be overcome by the use of siphon tanks.

The best of the gravity distributors (a 3-inch metal disk with a 2-inch radius of curvature) has given much better results than we had hoped for it. Without the complication of siphon tanks and varying head, it shows a corrected coefficient of .62, double that obtained for the Waterbury and Columbus nozzles under the same conditions. With a 4-foot total head its coefficient is .40, while the Columbus nozzle gives .22 with a similar constant head, and the best Columbus nozzle value with a varying head is only .43. The smallest opening for clogging in the gravity system is the discharge pipe, ¾ inch in diameter, while the diameter of the Columbus nozzle is $\frac{9}{16}$ inch. Furthermore, the accessibility of the whole distribution system makes its maintenance in good condition easy.

The new Salford and Birmingham pressure nozzles produce the most efficient distribution of any of the devices tested. At a 6-foot total head the Birmingham coefficient is .69, and at a 4-foot total head it is still better (.80), the distribution being almost perfect. These good results are, however, gained by the use of nozzles which are extremely liable to clogging. The openings of the new Salford nozzle are only $\frac{5}{32}$ inch in diameter, and the cone into which they discharge is admirably adapted to collect solid materials. The opening in the Birmingham nozzle is a ring only $\frac{5}{64}$ inch in diameter. Its removable plug indicates that even with the carefully screened and septicized sewage of Birmingham it requires frequent attention; and it is difficult to see how any such device could be economically used under American conditions, even with septic sewage. On the other hand, crude sewage can be sprayed by the Columbus nozzle or the gravity distributor without difficulty from clogging.

BOOK REVIEWS

Geology of Connecticut[1]

There has lately been issued by the State Geological and Natural History Survey of Connecticut two bulletins giving a *résumé* of the known geology of the state, with a geological map. Bulletin 6 is a "Manual of the Geology of Connecticut," by Professors W. N. Rice and H. E. Gregory; Bulletin 7, a "Preliminary Geological Map" of the state, by Professor H. E. Gregory and Dr. H. H. Robinson. The latter bulletin contains, besides a colored geologic map of four miles to the inch, a sketch of the history of Connecticut geology and a short summary of the formations found within the state. In Bulletin 6, of some 270 pages, the authors give a concise, generalized *résumé*, with such explanatory details as to make the book intelligible to the average lay reader, and the whole is written in a very interesting and simple style. The four chapters treat of the physiography, the crystalline rocks, the Triassic, and the glacial geology.

The authors first discuss the division of Connecticut geographically into the Eastern Highlands, the Western Highlands, and the Central Lowlands; the last is subdivided into a central range of trap hills, an eastern valley (in part that of the Connecticut River), and a western valley (the Farmington-Quinnipiac).

The foliation and faults of the Highland rocks extend approximately east of north to west of south; thus one of the most conspicuous features in the topography of the state is the approximately northeast to southwest trending ridges and valleys. This structure is appreciated when the location of the railroad lines is considered; those running north and south have no heavy grades, costly cuts, fillings, or bridges, while the east and west lines have been constructed and are maintained under great difficulties.

The rocks of the Highlands, mostly gneisses and schists, have been so strongly metamorphosed that so far as known all fossils have been

[1] Connecticut State Geological and Natural History Survey, Bulletins 6 and 7, 1907.

destroyed; this leaves their age in doubt except in those cases where a formation can be traced elsewhere into a fossil-bearing zone. It is thus known that the western portion of the Western Highlands rocks are of Cambrian age (Poughquog quartzite), Cambro-Ordovician (Stockbridge limestone), and Ordovician (Berkshire schist). The rocks of the eastern portion of these Western Highlands, as well as the entire Eastern Highlands, are of unknown age, though almost one-half are metamorphosed igneous.

The Central Lowlands are underlain by reddish brown sandstones and shales with intercalated igneous rocks, all of Triassic age. The red color of the strata, due to the ferric oxide in the cementing material, indicates that it was not deposited in the shallow sea along a coast, as the abundance there of life would afford so much decomposing organic matter as to reduce any ferric oxide present. It was most probably deposited in a tidal estuary, as many layers show mud cracks, raindrop imprints, and tracks of land animals, which were covered and thus preserved by the mud brought by the incoming tide.

The occasional presence of conglomerate along the margins of the deposits, with usually the sandstone and shale in the middle of the area, would indicate that the estuary was in places not much wider than the present extent of the Triassic. This coarse sediment is easily identified as derived from the gneisses and schists of the Eastern and Western Highlands, which then evidently formed the shores of this sinking, trough-like estuary.

Fossils are represented among plants by ferns, equisetes, and gymnosperms; among animals by a shell allied to the fresh-water mussel, numerous fresh-water fishes (many allied to the garpike), and extremely few bones but numerous tracks of amphibia and reptiles, many of the latter being dinosaurs.

Associated with the Triassic sediments are igneous rocks, trap consisting mainly of the minerals augite and labradorite. This trap occurs about halfway between the bottom and top of the sediment, principally in three extensive sheets; the lowest 250 feet thick, the middle and upper 400 to 500 and 150 to 200 feet thick, respectively. Beneath the lowest of these three sheets are one or more intrusive sheets, part of which forms the celebrated "four rocks" in the New Haven region. Through a later, eastward tilting of these rocks the trap sheets outcrop in north to south ridges, though owing to the north to south faults the number of the ridges is multiplied, while the northeast to southwest

faults of central and southern Connecticut, as also the minor anticlines and synclines, cause offsets in and a further multiplication of the ridges.

In the middle of the Western Highlands, in the Pomperaug valley, is an area of Triassic sediment which owes its preservation to the fact that it was dropped down by faults between the harder crystallines. This area, with its included trap sheet, was in all probability once continuous with that of the Connecticut valley.

The Triassic is estimated to have a probable thickness of from two to two and a half miles. At New Haven, which is situated upon the lower half of the formation, a well was sunk 4,000 feet without reaching the underlying crystallines.

The present area of Connecticut, at least its western portion, was probably beneath water from pre-Cambrian time through the Cambrian and Ordovician. The old land lay to the west of the state and east of the present continent, thus contributing sediment from both sides to this area. The subjection of this region to the mountain folding of the Silurian to the Trias gave its rocks their present crystalline character. The force producing the schistosity accompanying this crystalline character came from east of south, giving a steep southeast dip and a northeast to southwest or almost north to south trend. There are many local variations, however, as at Bristol, where the planes of schistosity lie in nearly every point of the compass so as to adjust themselves to the underlying rounded mass of granite gneiss.

At the beginning of Triassic times there thus probably existed in eastern and western Connecticut high mountains, between which lay a trough-like valley which later became an estuary. This down-sinking trough received the sediment washed from these mountains and remained approximately at sea level during the entire Triassic. In the middle of this era volcanic activity took place, resulting in some 1,000 feet of lava flows. Most of this probably flowed quietly forth from some fissures, but explosive phases also occurred, since tufaceous deposits are found both in southern Connecticut and near Mt. Holyoke, Massachusetts.

At the close of the Trias the region of the Central Lowland was raised above the sea, the rise being greater at the west than at the east. This gave the eastward dip to the Triassic beds, and it was evidently sufficient to cause the resultant Connecticut River to turn eastward at Middletown and flow upon the crystallines of the Eastern Highlands. The uplift was accompanied by a complex fracturing of the Triassic

strata and much of the crystallines, causing a series of block faults with usually the upthrow on the eastern side, producing a steep western slope (the fault scarp) and a gentle eastern (the dip of the beds). This gave to Connecticut in late Mesozoic times a topography quite similar to that of the Great Basin of the western United States at present. By the close of the Mesozoic the rivers and atmosphere had planed these block ridges and mountainous highlands down to a low, smooth peneplain.

At the beginning of the Tertiary there occurred an uplift with folding, the uplift being greatest (about one-half mile) in the northwestern portion of the state and sloping southeastward. The increased elevation gave renewed activity to the streams. These eroded into valleys, the softer sandstones and shales of the Triassic much more quickly than the harder trap and crystallines; thus resulted the broader features of the present topography — the Eastern and Western Highlands and the Central Lowland with its north to south ridges of trap.

During Quaternary times the entire state was covered by the continental glaciers, which planed off all partially decayed rock, leaving no gradual transition from solid rock to soil such as occurs in the southern states. At its departure it left the entire region covered promiscuously with glacial *débris*, thus obstructing and deflecting the old water courses and causing the many lakes and waterfalls of the present topography.

HERVEY W. SHIMER.

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BOOKKEEPING FOR CORPORATIONS[1]

THE title of this book naturally leads one to expect to find in it a full discussion of methods of accounting and management, and the reader is somewhat disappointed when he finds that it contains practically nothing but forms representing various kinds of securities, accounts, bills, reports, etc. A few definitions and a small amount of explanatory matter appear at various points in the work, but the explanations are often ambiguous and in nearly every case inadequate, while the definitions are far from satisfactory.

[1] Quasi-Public Corporation Accounting and Management. By John E. J. Mulhall Boston: Corporation Publishing Co., 1905. 198 pp., 8vo.

Viewed as a mere collection of forms the book is all that could be desired, and should prove very helpful to accountants in the lines covered. It would seem, however, that some description of the duties of the various officers in companies conducting the lines of business covered should have been included if the work is to justify its title. Moreover, it strikes one as rather anomalous that no scheme of business organization and no discussion of the functions of various departments, with their interrelations, should have been introduced into a work which purports to be a practical handbook on the organization and accounts of such large and important enterprises as water works, gas works, electric lighting works, electric railways, steam heating plants, and telephone companies. It appears to the writer of this article that the author of the book should either change the title of his work or revise it by incorporating an adequate treatment of the subject-matter which one has a right to expect in a book on corporation accounting and management.

C. W. D.

A Handbook of Petrography[1]

This little book by Dr. Weinschenk, Professor of Petrography at the University of Munich, is designed to present to students of geology the principles of petrography in as simple and attractive a manner as possible. No attempt is made to take up the microscopic characteristics of rocks, so that the book is in no sense one intended to take the place of the more extended treatises on the subject, but is essentially a book which will serve as a guide during the first systematic study of rocks in the field and laboratory. The hope is expressed that the subject as presented will serve to incite the student to pursue further the study of this interesting but somewhat difficult subject.

The book is divided into two parts. The first, or general part, is devoted to a brief but quite satisfactory discussion of subjects, a clear understanding of which is essential for the proper classification of rocks; for example, observations on the general structure of igneous rocks, particularly as affected by their mode of occurrence; the characters of "Contact" rocks and of the crystalline schists; observations on the sedimentary rocks; suggestions regarding the study and classification

[1] Petrographisches Vademekum. Dr. Ernst Weinschenk. Freiberg in Br.: Herder, 1907. St. Louis, Mo.: B. Herder. 208 pp., 98 il. 85 cents.

of rocks in the field, in connection with which a table is furnished as an aid. The first part is concluded by a chapter giving a brief description of the common rock-forming minerals as they are observed in practice.

The second, or special part, is concerned with the description of important rock types. About seventy pages are devoted to the igneous rocks, which come first, and about the same number to the sedimentary and metamorphic rocks. After a brief discussion of the chemical compositions of the important rock-forming silicates and of the principal divisions of the igneous rocks, these latter are taken up under four heads, as follows:

I. Orthoclase rocks, those in which orthoclase is the predominating constituent.

II. Plagioclase rocks, those in which plagioclase is the predominating constituent.

III. Soda rocks, those which are characterized by a predominating amount of sodium.

IV. Feldspar-free rocks.

With each species described under these divisions the order followed is: external characters; mineral composition; geological occurrence.

With one or two exceptions the definitions of the various types of igneous rocks will meet the approval of teachers of petrography. English and American petrographers will differ, perhaps, from Dr. Weinschenk in the restricted meaning which he assigns to the term basalt, viz., those dark-colored, finely crystalline or aphanitic rocks, rich in sodium, and would prefer to extend the use of this term to cover also most of those rocks for which Dr. Weinschenk uses the term trap. Some teachers would also prefer to take up the nepheline-syenites as a subdivision of the syenites proper, believing that such treatment is simpler, at least for field use.

The sedimentary rocks are taken up in the following order:

I. Mechanical sediments.

II. Chemical sediments.

III. Sediments of organic origin.

Under each variety we find a discussion of the macroscopic characters, mineral composition, and geological occurrence.

Individual descriptions throughout are brief, concise, and to the point; the illustrations are uniformly excellent and are well chosen; the typographical work is admirable, and the book is of a convenient pocket

size. The use of the book in this country will doubtless be limited on account of its being written in German. It is, however, to be especially recommended to students who intend to pursue advanced geological studies, not alone for its petrographical merit, but for the familiarity with German petrographical terms and usages.

C. H. WARREN.

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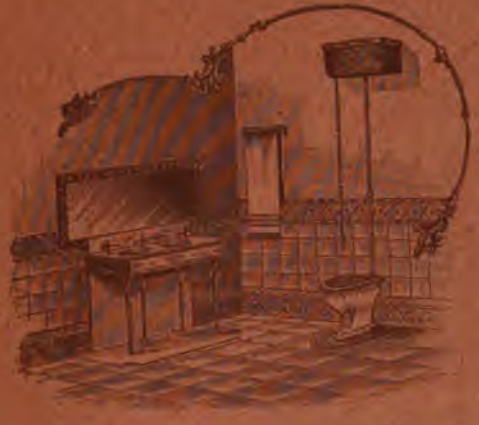

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TECHNOLOGY QUARTERLY

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RELATION OF THE MINING SCHOOL TO THE MINING INDUSTRY[1]

By ROBERT H. RICHARDS

It is taken for granted that the mining industry is the chief thing and that the school exists to help the industry. A difference of opinion may exist as to how this should be done.

The mining industry has such a strong bearing on the welfare of the community that it is well to dwell upon this relationship a moment before taking up the main thread.

The miner brings the ores to the surface; the smelter separates the metals — metals without which there can be no advancement in the community, no civilization.

What did the stone age man have? A stone hammer, a stone knife, a stone arrowhead, a tent of skins. He had advanced as far as he could without metals. We are so accustomed to use metals and articles manufactured of metals, or by means of them, that we do not think of the immense advance that has been made in consequence of the work of the miner and metallurgist, and of the wonderful age in which we live.

If we look about this room every metallic object in sight has been made from ore got by the miner and refined by the smelter. Every

[1] Read before the American Mining Congress at Joplin, Missouri, November 11, 1907.

object in wood, glass, pottery, plaster, cement, or other material than metal has been gathered, shaped, and finished by tools of metal. And again, the business of mining and metallurgy furnishes a great field for gaining a livelihood. Great numbers of men are employed in the ranks of labor and of the skilled mechanic; considerable numbers also in engineering, management, financing of mines; also in the mercantile pursuits to furnish supplies. Finally, as an investment of funds, the successful mine is among the most profitable of investments, and the unsuccessful mines may be no worse for the stockholder than the unsuccessful railroad or manufactory.

The points of contact between the community and the mining industry are then varied in kind and many in number. For economy in the world's work, for the best results in quickest time, all forces tending toward the same end should work in harmony, each doing its own part. This is the case with the mining industry and the mining school.

Mining plants should be ready to supply to students certain necessary experience which the school cannot give — hence the need of mine practice; but they cannot do the whole work without great waste of time — hence the need of the school training. There should be a cordial relationship between school and mine.

The school asks the mining industry to take its pupils and be patient with them for a little time until they acquire the experience with men in command and men employed — things that no school can teach. A few vacation months at a mine, mill, or furnace is worth a great deal to help a student appreciate the value of his school work, to clinch his knowledge, to make it a useful tool, and to work off his crudity.

The universal verdict is that a student leaving a school should spend a year or more at work at mines or furnaces, doing laborers' or mechanics' work. He not only gains by contact the knowledge of things which the school failed to give him, but, and still more important, he gains knowledge of men. A man to direct others must know what the other man is thinking of. The young man who began as a laborer knows this from his own experience. The young man who did not so begin is at a great disadvantage. Therefore we ask the works and mines to have a little patience with the young beginners just out of school. Many works are already doing this in a very liberal way. And I wish here, in behalf of the schools, to present our thanks to those in charge

of the mining industry for the fine way they are doing this. We ask, further, that those in charge of industry forgive the occasional misfit which the young schoolman makes, and that they do not charge off his misdemeanors and mistakes as a universal attribute of schoolmen.

Besides the knowledge of things by contact that a student can learn at the works, the sense of responsibility he acquires is of immense value. It is impossible to give in the school the sense of impending fate which impresses facts on the brain in mines and furnaces. A furnace man must get his 300 tons a day smelted or lose his job. A miner must get his pump running in three hours or the pump will be drowned and the mine flooded. This kind of active work and experience is a great teacher.

What, now, may the school do for the works in return for favors received? Those in active work, with the constant and incessant demands upon them, have little time to investigate problems and to seek for the underlying principles on which the most perfect solution may depend, or to find what others at a distance are doing in the same line; and if they are self-made men they are probably wise in experience but weak in mathematics. In most mines there have been short periods of depression because of failure to grasp some salient point which a trained engineer would have seen.

The school teaches the alphabet of machinery and processes and fundamental knowledge, just as useful here as the real alphabet is in looking out words in a dictionary. The mining school cannot give the experience, but can give the training in mathematics, physics, chemistry, and drawing; and it can give the pupil access to the accumulated fund of professional methods of all time. This leads us up to the school's main duty to the mines and works. If a school can inspire enthusiasm for the profession in its pupils, and can bring the pupils to the point where they have love of knowledge, love of accuracy, love of industry, it has led its pupils to a point where they are ripe to become engineers, for they will be naturally seeking problems to solve and solving problems when found — problems in excavating, in sorting, in tramming, in hoisting, in dealing with men; problems in moving materials, in concentrating ores, in economy of waste, in re-treating waste, in dealing with the market, in handling the property to the advantage of the owners, and, indirectly, of the community.

The student must acquire a love of knowledge, a love of accuracy, and a love of industry. We expect the school to develop this in him.

How can the school do this? It can only do it by making the problems the school sets before the pupil real, live, interesting ones. A real problem as new to the teacher as to the pupil has the greatest power to awaken enthusiasm in the pupils. Every small problem solved in the school laboratory whets the appetite for greater ones in the field.

The school has to make things real to most of its pupils, who have never seen a mine. The pupil who goes to the school from the mining region, while he is an apt pupil and interested in the profession, is unbalanced by giving more value to the details in his own district than to fundamental principles. He must be balanced up by showing him the value of fundamental principles and the differing practice of other districts. The school must be organized to help both kinds of students. One of the best things the mines and works can do for the schools is to let the teachers know some of the real problems with which the profession is struggling. This can well be done when the teachers bring their students on visits. The teachers can get in this way into the spirit of the game and carry back problems to work over at the school, thus gaining inspiration for their work which they pass on to their students. Furnish them specimens, samples, drawings, photographs. Students become immensely interested in actual needs if something they do is going to count. It makes the profession a real, living interest to them.

The school contributes to the success of the mining industry; the mining industry is vital to the success of the community, and therefore the community must support the mining school.

CONTRIBUTION FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE IN SEPTIC TANKS AND TRICKLING FILTERS (1905-1907)

BY C.-E. A. WINSLOW AND EARLE B. PHELPS

I. RESULTS OF PREVIOUS INVESTIGATIONS

THE Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology was founded in 1902 by an anonymous donor for the purpose of making experiments upon improved methods of sewage disposal, especially those adapted to large cities. A large part of the work of the staff has been devoted to the study of the more purely scientific problems — chemical, bacteriological, and hydraulic — which underlie the practice of sewage analysis and sewage purification. We have carried on, however, along with these theoretical investigations, an experimental study of the immediate local problem of sewage disposal, as it is certain some day to confront the city of Boston.

The sewage of the Metropolitan district of Boston is at present discharged, untreated, into the waters of the harbor at three different points. The main outfall sewer of the north district carries some fifty million gallons daily, and discharges continuously off Deer Island. The sewage from the high level district passes out to Peddock's Island, near the southeastern limit of the harbor; this amounts to about twenty million gallons. The main outfall of the south Metropolitan district is at Moon Island, nearer the centre of the harbor, and here the sewage is stored in masonry tanks and discharged only on the turn of the tide. The daily flow in this sewer is in the neighborhood of one hundred million gallons. The Massachusetts State Board of Health investigated the condition of Boston Harbor in 1905 (Goodnough, 1906), and found no serious damage from this method of disposal. The town

of Wellesley has, however, recently been refused admittance to the Metropolitan system from fear of overtaxing the purifying power of the harbor (Wellesley, 1907);[1] and it can scarcely be doubted that the progressive increase of population within the drainage district itself will ultimately bring the problem of sewage purification to the fore. The present agitation in regard to the pollution of New York Harbor (Whipple, G. C., 1907) under somewhat similar conditions is an indication of what must some day be expected in Boston.

Under these circumstances it is important to form a general idea beforehand of what a proper purification of Boston sewage will involve; and the investigations at the Sanitary Research Laboratory have reached a point at which this can approximately be determined. It should be understood that neither state nor municipal authorities are responsible for the conclusions which follow. The investigations here reported proceed wholly from the Sewage Experiment Station of the Institute, and deal with a coming problem, not a present one. It is hoped, however, that they may yield data of importance in determining the feasibility of a disposal project when the time for installing one shall come, and offer some guidance as to its probable final form.

The first essential in planning for sewage disposal is a knowledge of the special characteristics of the sewage in question. In a previous communication (Winslow and Phelps, 1905) we have discussed this point somewhat fully. The sewage of the south Metropolitan district, with which we dealt in our experiments, is that which flows from the combined system of the city of Boston proper. It is a typical American domestic sewage, of average strength, and in 1903 morning samples showed an average of about six parts per million of nitrogen as albuminoid ammonia, eighteen parts of nitrogen as free ammonia, and forty-five parts of "oxygen consumed." Suspended solids were at this time somewhat under 150 parts per million. We have pointed out in the paper above cited that the average analysis of the whole twenty-four hours' flow was about 80 per cent. as strong as the morning sewage.

A preliminary series of investigations covering the various methods of purification in common use was carried out from 1903 to 1905. Septic tanks, contact beds, sand filters, and trickling filters were studied, each unit being a cypress tank of 72 to 96 cubic feet capacity, and the results have been fully presented in a previous communication

[1] It is understood that this action was taken in view of the fact that Wellesley lies outside the area previously fixed upon as properly tributary to the Boston outfall.

(Winslow and Phelps, 1906). These studies led to certain general conclusions which may be summarized as follows:

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 16,000 pounds (.65 cubic yard) per million gallons of sewage, and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected, if desired, by treatment in the septic tank. In our experiments an open tank operated as well as a closed tank. Varying the storage period from twelve to forty-eight hours produced no difference in the effluents which was measurable by analytical results. The tanks studied removed nearly two-thirds of the suspended matter and yielded an effluent which was clear, but much darkened by sulphides. The tanks on an average received fifty pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which thirty pounds were discharged in the effluent, fifteen to seventeen pounds decomposed, and three to five pounds stored as sludge. In the decomposition of sludge the length of the septic period was of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed was twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments, crude Boston sewage was successfully filtered through a 2-foot bed of sand with an effective size of .14 mm., at a rate of .4 million gallons (400,000 gallons) per acre per day, divided into four doses in the twenty-four hours. Such high rates should not be expected in actual practice, with outdoor beds, particularly during the winter months. In communities with limited sand areas much might be accomplished, however, by frequent cleaning of the surface of the beds; and it is interesting to know that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds in these experiments were clear, bright, and well purified. Preliminary septic treatment for twelve or twenty-four hours did not improve the effluents obtained with sand filtration, although it made the care of the surface of the beds somewhat easier.

It was found that crude Boston sewage could be treated in single-contact beds of fine stone (½ inch in diameter) at a rate of about

1.2 million gallons per acre per day. The effluent, though only partially purified, was generally so stable that it could be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clogged rapidly and the surface needed much attention. The double-contact system of treatment, in primary beds of 2-inch material and secondary beds of ½-inch material, yielded a fairly well purified and

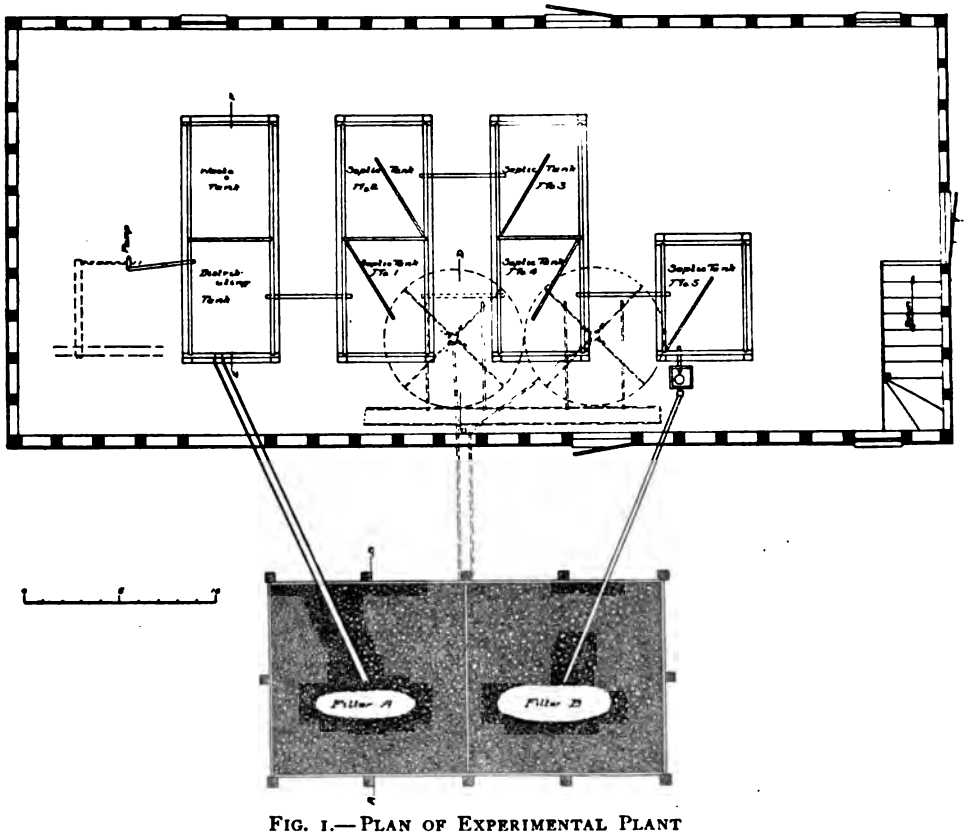

FIG. 1.—PLAN OF EXPERIMENTAL PLANT

stable effluent at a rate, on the combined double system, of about 0.7 million gallons per acre per day, with beds 6 feet deep. This system clogged much less seriously, but nevertheless lost sufficient capacity to require renewal every few years. Preliminary septic treatment obviated this loss of capacity to a considerable extent.

Experiments with continuous, trickling, or sprinkling filters showed results equal to those obtained with the double-contact system at much

higher rates, and suggested that this method would probably prove the most practical of all. Three such tanks were studied, one from 1903 on and the other two in 1904 and 1905. They were operated at rates between 1.5 and 2.5 million gallons per acre, producing turbid but fairly stable effluents, and were entirely free from surface clogging. To base conclusions as to the efficiency of trickling filters upon tanks only 16 square feet in area, dosed with tipping buckets and operated under

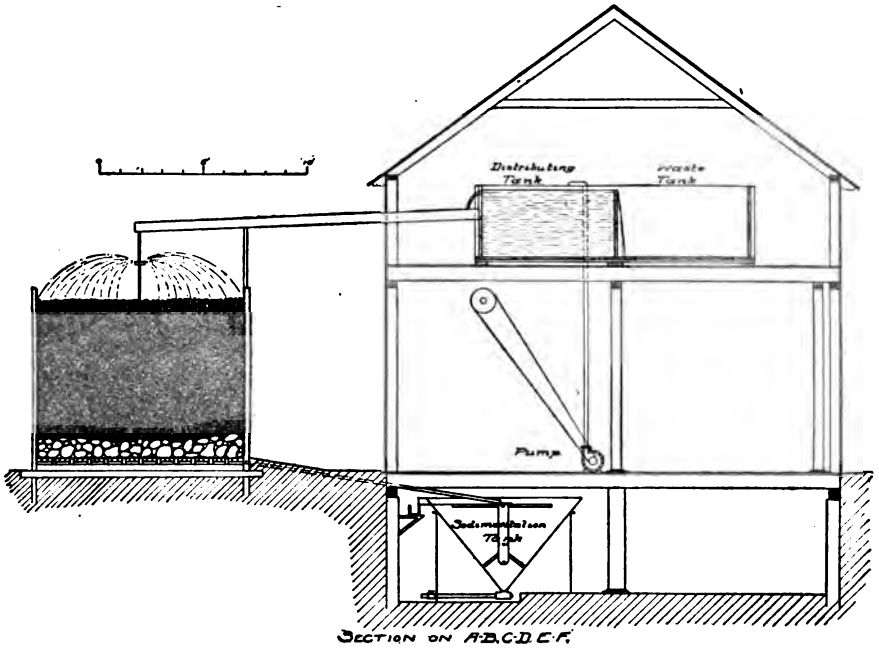

FIG. 2.—SECTIONAL ELEVATION OF EXPERIMENTAL PLANT

cover, seemed, however, unwise. For such a general survey as was contemplated in our preliminary work, and particularly for studies of contact beds, small indoor filters are of value; but the two important points in the operation of the trickling filter are the system of distribution and the effect of winter conditions, neither of which can be studied on a small scale. We therefore constructed in August, 1905, an outdoor filter of adequate size, which has been successfully operated for nearly two years; this has yielded results which we believe to be representative.

II. Description of the Experimental Plant

The Sewage Experiment Station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany Street and Massachusetts Avenue. It includes a small, two-story laboratory building, a two-story tank house, and the trickling filter. Septic tanks and sedimentation basins are placed inside the tank house. The general arrangement of the tank house and filter is shown in Figures 1 and 2.

Sewage for the use of the station is obtained from the 9-foot trunk sewer of the Boston Main Drainage Works at a point where there is a flow of some fifty million gallons a day from a contributing population of 250,000. It is raised by a 4 × 6 Warren duplex pump, being roughly settled on the way by passage through a grit chamber, 19 inches in diameter and 16 inches deep, fitted with a screen whose bars are ½ inch apart. The sewage is then raised, without further sedimentation, by a ¾-inch centrifugal pump to the distributing tank, shown in the plan and section, Figures 1 and 2. No sludge was removed from this tank, and the inflow was kept always in excess of the outflow, a constant head being maintained by wasting over a 36-inch weir at one end. From the opposite end of the distributing tank sewage flowed to one of the trickling beds, filter A, over a 1-inch brass weir, the crest of which could be raised or lowered by a micrometer screw. By regulation of this crest in relation to the constant height on the waste weir it was possible to obtain any desired flow on the filters. A depth of about 1 inch on the small weir corresponded to 200 gallons per hour, or 2,000,000 gallons per acre per day, the rate in use for the past two years.

From one side of the distributing tank sewage flowed continuously through a short length of 2½-inch iron pipe to the first of the septic tanks. These were open cypress tanks, 6 × 4 feet × 3 feet deep, connected in series by 2½-inch iron pipe.

The general arrangement of the septic tanks is indicated in Figure 1. Only Nos. 1, 4, and 5 were used during the first twelve months of the investigation. In October, 1906, the direct connection between 1 and 4, and 4 and 5, was cut off and Nos. 2 and 3 brought into the series. The distributing tank and all five septic tanks have since that time been in open connection, the level in all being controlled by the large waste weir of the distributing tank. The septic tanks were

provided with wooden baffles, arranged as shown in Figure 1. The total capacity of the septic system was equal to twelve hours' flow, and its division into five separate tanks made it possible to study successive stages in the septic process. From the last tank, a 1-inch

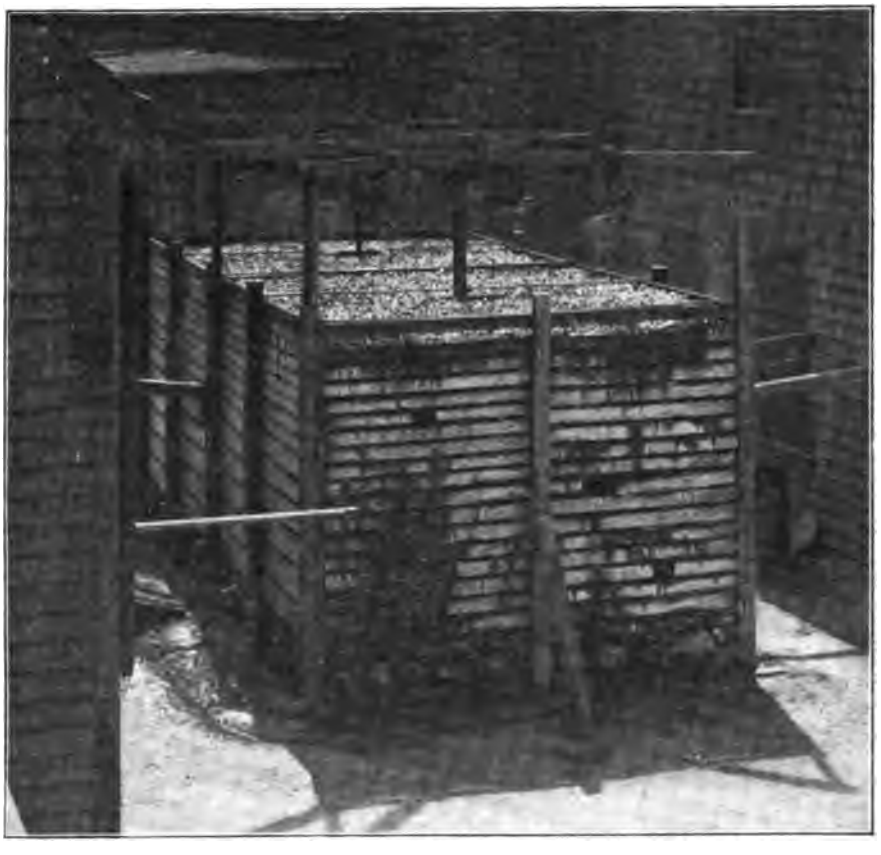

FIG. 3.—VIEW OF EXPERIMENTAL TRICKLING BEDS

brass weir, exactly like that on the distributing tank, regulated the flow on the second trickling bed, filter B.

A general view of the trickling beds is shown in Figure 3. The combined superficial area of both beds was 200 square feet, and the depth 8 feet. A central partition of 2-inch spruce planking, with matched joints, divided the total area into two separate beds, each 10 feet square. Filter A treated crude sewage and filter B septic

effluent. Both beds were filled with crushed stone, granite, and trap, between 1½ and 2 inches in diameter.

The construction of the filters was as follows: For a foundation, 4 × 4 inch spruce beams were buried in the ground, with top surfaces flush. A hemlock floor 1 inch thick was next laid and covered with a layer of 1 to 2 Portland cement mortar, 1 inch thick at the inner corner of the filters near the tank house, and sloping up to a thickness

FIG. 4.—UNDERDRAINAGE SYSTEM OF TRICKLING BEDS

of 3 inches at the opposite side. Four radiating channels in the cement, ½ inch deep, aided the flow to the inner corners, from which the effluent was conducted into the tank house by 1½-inch iron pipes, 8 feet long, with a slope of about 1 foot. The sides of the filter (Fig. 3) were of spruce planks, with ½ to 2-inch openings between them, the lower 18 inches being entirely open. These sides were supported by 4 × 4 inch uprights, braced on all sides and tied at the tops by ½-inch iron rods. On the cement floor two layers of brick were laid in open

courses, as shown in Figure 4, to ensure good underdrainage. On these were 18 inches of bowlders and 65 inches of the main filling material — 1½ to 2-inch crushed stone.

For spraying sewage over the surface of the filter a new method was devised, which we have called the system of gravity distribution. This was described by us a year ago (Winslow and Phelps, 1906 *b*), and has since been adopted by the Massachusetts State Board of Health for its experimental filter at Andover (Clark, 1907). In this system a fine spray is produced, not by throwing the sewage up into the air from a fixed nozzle, but by discharging it downward from an opening in the bottom of a trough on to a concave metal plate, from which it splashes upward. The plan first adopted allowed four such splashing disks for each of our two filters. During this period the arrangement of the system was as follows:

The sewage from the two dosing weirs, in the distributing tank and in the septic tank No. 5, flowed out from the tank house through open wooden troughs, 3 inches in width and 3 inches deep. From these the sewage dropped into similar troughs, which ran from corner to corner of each of the two filters, joining at the centre in the form of a cross. The sewage passed into this cross at its centre, flowed out into the four arms, and dropped through ¾-inch holes to the disk distributors, four to each bed, 100 square feet in area. In each hole was a 3-inch piece of ¾-inch brass tubing, threaded on its upper inch and screwed to a lock nut inside the trough. Any inequality in distribution due to change in the level of the distributing troughs was easily corrected by changing the position of this short tube. Below the troughs the stream of sewage was protected from the wind by a box extending down for 12 inches, and at 15 inches below the trough the stream struck a shallow concave disk, from which it splashed outward. On the filter, as operated during the first year, these disks were 3 inches in diameter, and their concavity had a 6-inch radius. Each was held in place by four ¼-inch brass rods. The general arrangement of this distribution system is shown in Figure 3. It worked with fair success, breaking up the sewage well, and not requiring an excessive amount of attention. Some difficulty was experienced during the winter of 1905–06, but the beds remained in operation. On the coldest days an umbrella of ice surrounded each disk, somewhat limiting the surface distribution; but within this shield the spray worked well.

With disks spaced in this manner, however, there were considerable

intermediate areas of the filter which did not receive sewage, while the portions directly under the disks were operating at excessive rates. During the summer of 1906 pooling occurred on the raw sewage side, and in November of that year we substituted for the four splashing disks

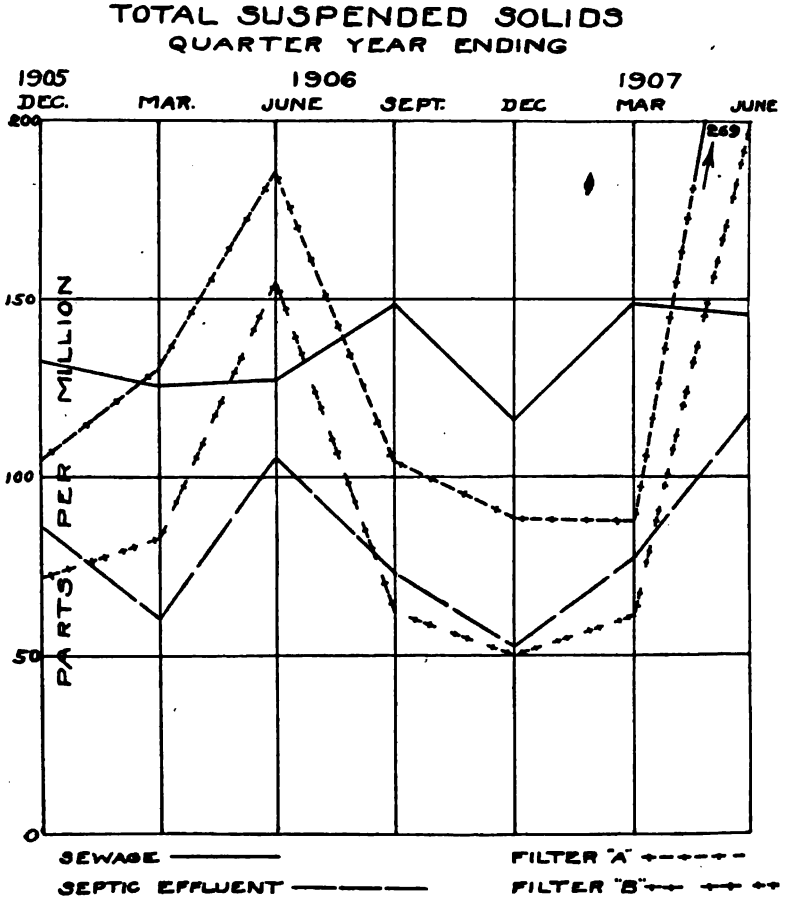

FIG. 5.—QUARTERLY VARIATIONS IN TOTAL SUSPENDED SOLIDS; SEWAGE AND EFFLUENTS

on filter A a single splashing disk of the same type, placed at the centre of the square. This single disk, with four times the discharge upon it, gave a much better distribution over the 10-foot square than its four predecessors. A detailed study of the efficiency of various trickling filter distributors (Winslow, Phelps, Story, and McRae, 1907)

has shown that this type of splashing disk gives more even distribution than any other device, except certain complicated pressure nozzles with small openings. For purposes of comparison we installed on filter B a pressure nozzle of the type used in the early experiments at Columbus, Ohio. This has "a single orifice, $\frac{9}{16}$ inch in diameter, with rounded edges, above which, held by two thin arms, is an inverted

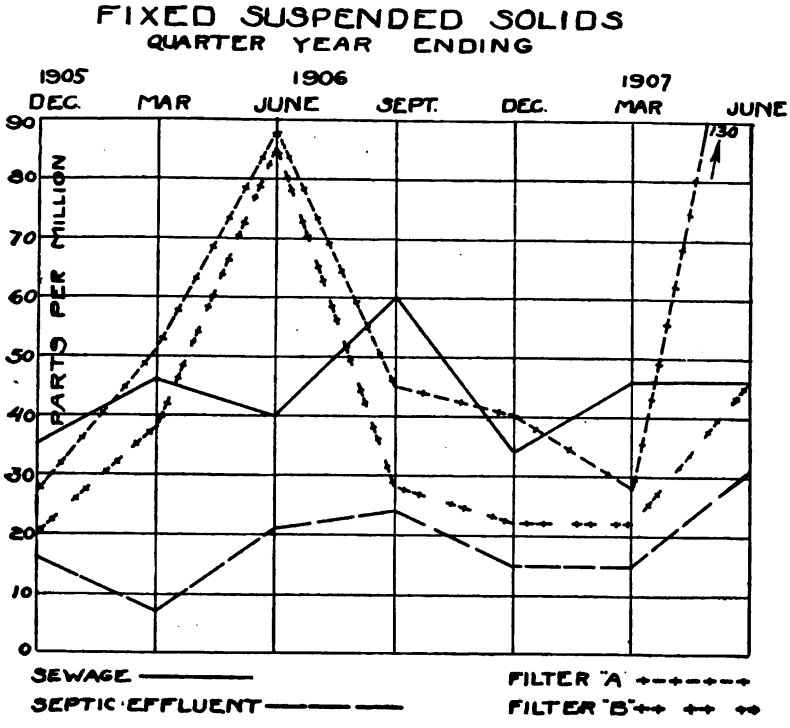

FIG. 6.—QUARTERLY VARIATIONS IN FIXED SUSPENDED SOLIDS; SEWAGE AND EFFLUENTS

90° cone, the axis of the cone coinciding with the axis of the orifice. The jet on leaving the orifice impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops" (Gregory, 1906).

A nozzle with an orifice as large as that of the Columbus sprinkler, when operated with a 4-foot head, as in our experiments, produces an excessive discharge. We therefore placed a dosing chamber between septic tank 5 and filter B, equipped with an automatic, air-locked

siphon, discharging at a head of 4 feet and cutting off at 3 feet. Ball floats operated the air valves, which started and cut off the siphon sharply at the beginning and end of its discharge. In operation, the siphon tank filled in one minute twenty-six seconds, and took one minute ten seconds to empty. It discharged through a 2-inch pipe, which passed into filter B about 6 inches below its surface, rising again at the centre of the bed just above the level of the stones.

The effluent from each filter, as pointed out above, was conducted by the sloping cement floor to the inner corner of each bed, thence flowing through 1½-inch iron pipes to the lower floor of the tank house. Since January, 1906, the effluents from the filters have been sedimented in tanks of special design (see Figs. 2 and 19). Each was a simple inverted cone, with a diameter at the top of 7 feet 2 inches and a height of 4 feet. This form was not so favorable for sedimentation as the Dortmund tank, with sides parallel in the upper part, but was adopted to suit the head room and area at our disposal. At the centre of each tank a vertical tube, 6 inches in diameter, extended to within 1 foot 3½ inches of the bottom. Into the top of this tube the filter effluent was discharged, its velocity being checked by a 3-inch conical cup. The liquid passed out into the tank near the bottom of the tube through openings in its sides. Sludge was removed once a day or once in two days from the bottom of the tank by the valve shown in the diagram. The supernatant liquor rose and overflowed through two 2 × 3 inch collecting troughs. The capacity of each tank was such as to give a two hours' storage period when the filter was running at a rate of 2,000,000 gallons per acre per day.

III. Methods of Sampling and Analysis

All chemical examinations were of composite samples. Portions were collected every three hours, day and night, and at once chloroformed; these were mixed and analyzed at the end of each week. One composite sample of the sewage and of each effluent was analyzed each week for the whole period of investigation.

Turbidity and sediment were observed in each sample by the use of the Jackson turbidimeter recalibrated for coarse material (Phelps, 1905). Total and fixed solids were determined by the Gooch crucible method of Kimberly and Hommon (1906).

Total organic nitrogen values were obtained by a modified Kjeldahl

method, previously described (Phelps, 1905), and during the last year nesslerizations have been made directly by a method devised by Whipple at this laboratory (Whipple, L., 1907).

Free ammonia was read by direct nesslerization against permanent standards. For nitrates the brucine method was used (Farnsteiner,

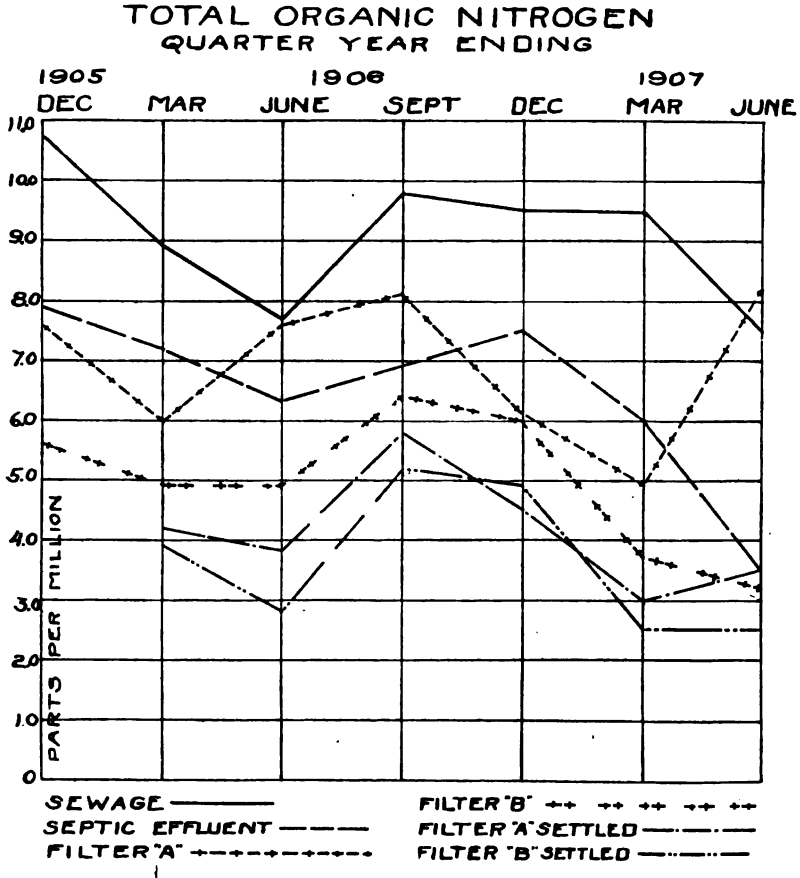

FIG. 7.—QUARTERLY VARIATIONS IN TOTAL ORGANIC NITROGEN; SEWAGE AND EFFLUENTS

1902). "Oxygen consumed" was determined after thirty minutes' heating on the water bath. This determination, and all others not specifically mentioned, were made according to the standard procedure recommended by the Committee of the American Public Health Association (1905).

Experience with the newer processes of sewage treatment has made it clear that the ordinary methods of analysis are insufficient by themselves to furnish all the information necessary with regard to the char-

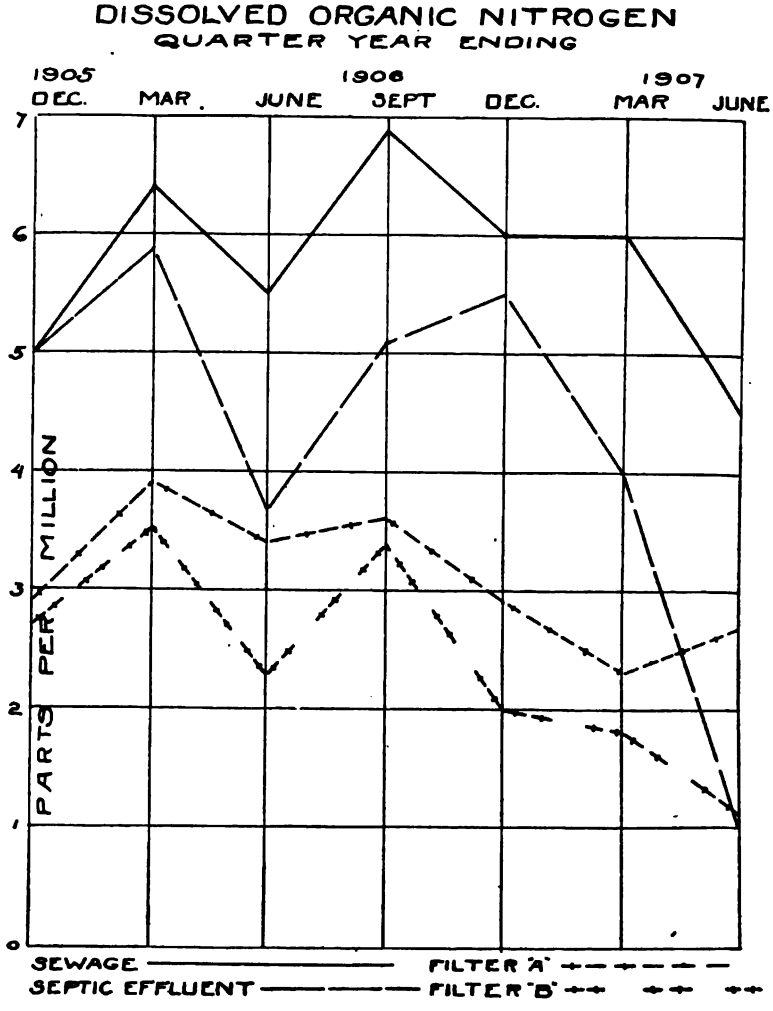

FIG. 8.—QUARTERLY VARIATIONS IN ORGANIC NITROGEN IN SOLUTION; SEWAGE AND EFFLUENTS

acter of a sewage effluent. Our knowledge of sewage cnemistry has not yet made it possible to discriminate clearly between putrescible organic matter and those more stable "humus-like" compounds which

do not undergo putrefactive decomposition. With intermittent sand filters, effluents are obtained which contain only a small amount of organic matter of any sort; and the purity of such effluents is easily demonstrable by oxygen consumed and nitrogen determinations. With effluents from contact and trickling filters, on the other hand, the ordinary analytical data do not offer a complete criterion of quality. An effluent may contain a considerable amount of organic nitrogen and give a high value for oxygen consumed, and may yet prove of excellent quality because its organic matter is in a stable form. In such cases it becomes necessary to supplement sanitary analysis by some practical test of keeping quality. Such a test, if its technique is easy, can be made to advantage at more frequent intervals than the more elaborate chemical examinations; and in small plants, where the latter are out of the question, it alone may prove of considerable value.

Although the terms putrescible and non-putrescible stand for quite definite characteristics, yet the separation of effluents of various degrees of purity into these two classes depends to a considerable extent upon the test employed for the purpose, and none of the older tests for stability has proved wholly satisfactory. The "smell test" is inexact, and at the other extreme the determination of oxygen consumed, dissolved oxygen, nitrates, and nitrites is too cumbrous a process for routine work. Furthermore, it does not accurately measure the relation of oxidizable matter to available oxygen, since the oxygen consumed by permanganate bears a variable relation to the organic matter which is oxidizable under natural conditions. The "Manchester test" is somewhat more satisfactory; but this, too, yields abnormal results at times, and only divides effluents into two rough classes, without distinction as to their relative grade.

A new putrescibility test, simple in technique and measuring accurately and delicately the relation between available oxygen and oxidizable matter, has, therefore, been a desideratum. Such a method appears to be at hand in the methylene blue test, first devised by Spitta (1903) for the study of stream pollution, and later more thoroughly worked up by Spitta and Weldert (1906) as a test for sewage effluents. The technique employed is extremely simple. A small portion of an aqueous solution of the dye (in our experiments 1 c.c. of a .1 per cent. solution) is added to the effluent in a glass-stoppered bottle (250 c.c. capacity in our work), and the sample is then incubated either at

20° C. or at 37° C. The blue color of the solution remains practically unchanged during the period of observation until the available oxygen contained is used up and putrefactive conditions arise. At this point the dye is reduced and decolorized. The time required for decolorization is a quantitative measure of the degree of putrescibility of the

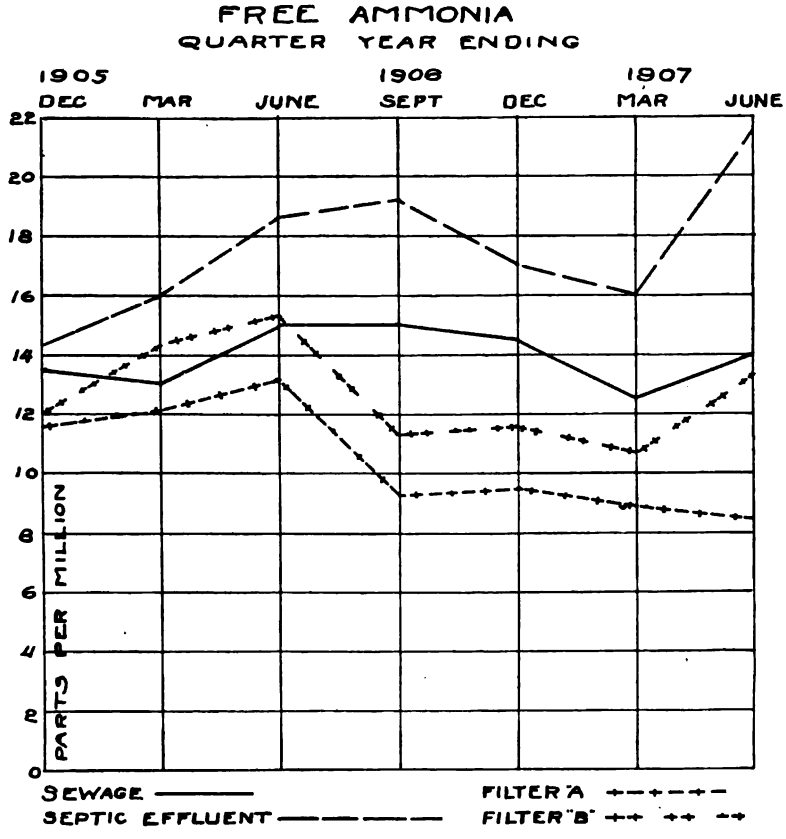

FIG. 9.—QUARTERLY VARIATIONS IN FREE AMMONIA; SEWAGE AND EFFLUENTS

sample, and the retention of the color for a period of four days or more at 20° C., or of two days at 37° C., may be taken as an indication of good stability. The criticism of Johnson, Copeland, and Kimberly (1906), that "substances other than putrescible organic matters, such as sulphide of iron and hydrogen sulphide," discharge the color of methylene blue before the putrescible matters themselves are able to act, does not

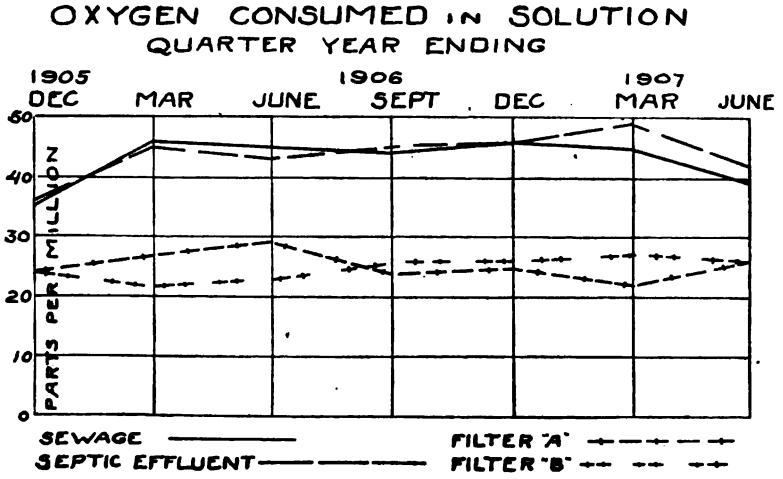

FIG. 10.—QUARTERLY VARIATIONS IN "OXYGEN CONSUMED" IN SOLUTION; SEWAGE AND EFFLUENTS

seem to us well taken, since such substances are present only when the effluent as a whole is in unstable condition.

Spitta and Weldert state that putrefaction occurs from two to four times as fast at 37° as at the ordinary room temperature. We have made a somewhat fuller study of this temperature factor and of some other points in connection with the methylene blue test, which have been reported elsewhere (Phelps and Winslow, 1907). For twenty samples of trickling filter effluents, the decolorization times at 20° and at 37° were determined to the nearest half day, and the ratios of the 20° times to the 37° times are tabulated in Table I. The actual number of days varied from half a day to thirteen days at 37° C.

TABLE I—RATIO OF TIME REQUIRED FOR DECOLORIZATION OF TRICKLING FILTER EFFLUENTS AT 20° TO THAT REQUIRED AT 37° C.

2.5	2.0	1.6	1.6
1.5	2.6	1.0	0.5
2.7	2.0	4.0	2.2
1.8	2.0	2.0	2.3
1.4	1.9	2.4	2.0

With the exception of two very low ratios (.5 and 1) and one high ratio (4), all these figures fall between 1.4 and 2.7, and the average of

all is exactly 2. It may be considered, therefore, that methylene blue samples will generally decolorize at 37° in half the time required at 20°.

It must be remembered in interpreting this table, and all others in which comparative decolorization tests are recorded, that each test must be made in a separate bottle; and since the sampling of sewage is never perfect, there will be variations due to chance differences in the several bottles compared. This is particularly true in work like that later cited in Table III, in which decolorization tests were made in one bottle and analytical data determined on another.

In general, it appears from Table I that results obtained at 20° bear to those obtained at 37° the ratio of 2 to 1. Stable samples are stable at any temperature. In grading putrescible samples, however, it is evidently necessary to select one temperature and to use it for all comparative work. The temperature of the body has the advantage that it gives results more promptly. Any sample which does not decolorize in four days is certainly stable, and a two days' limit would include almost all putrescible effluents. The 20° method, however, from the very fact that it is slower, permits a more delicate measurement of the relative differences between putrescible effluents of different grades. Decolorization here may occur from the first up to the fourteenth day. Slight variations from 20° will not introduce a serious error in the test, and diffuse daylight does not appreciably interfere with it. A series of control experiments made in daylight, in a box at the room temperature (in summer), and in an incubator at 20°, are recorded in Table II, and indicate that the test could be made in an ordinary room with fairly controlled temperature. Experiments made during cold weather in a small frame building heated by a stove showed marked abnormalities, on the other hand, and emphasize the fact that temperature variations cannot be allowed to go too far.

TABLE II — EFFECT OF TEMPERATURE AND LIGHT ON METHYLENE BLUE TEST

Average Time of Decolorization in Days

Week ending	Effluent A.			Effluent B.			Effluent C.		
	Summer temperature.		20° dark.	Summer temperature.		20° dark.	Summer temperature.		20° dark.
	Daylight.	Dark.		Daylight.	Dark.		Daylight.	Dark.	
June 27	1	2	2	11	11	7	2	3	3
July 2	3	3	3	12	12	10	3	3	4
July 9	2	2	2	2	3	2	2	3	3
July 16	2	3	2	9	12	10	13	13	13
July 23	2	3	4	7	8	7	14+	14+	14+
July 30	2	5	6	13	14+	13	12	14+	13
August 6	2	3	3	6	6	6	14+	13	13
August 13	3	5	4	13	13	12	13	13	13
August 20	10	5	5	14+	14+	14+	14+	14+	14+

With regard to the significance of the methylene blue test in relation to the specific chemical changes which go on in putrefaction, Spitta and Weldert have little to say, beyond pointing out that decolorization takes place only after all the available oxygen has been exhausted, which point they illustrate by a single experiment. We have studied the relation between decolorization and chemical processes a little more fully, and the results of the examination of five samples of trickling effluents are shown in Table III.

TABLE III—OXYGEN CHANGES IN PUTRESCIBLE TRICKLING FILTER EFFLUENTS

Decolorization of Methylene Blue Indicated by *

(Parts per Million)

Sample.	Days at 37°.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
			Nitrates.	Nitrites.	
1	Initial	8.0	3.0	1.0	5.0
	1*	0.0	0.0	0.3	5.0
	2	. .	. .	0.1	. .
2	Initial	10.0	3.0	1.0	4.0
	1	1.0	3.0	1.0	4.0
	2	0.0	0.0	1.0	3.4
	3	0.0	. .	0.1	4.0
	4	. .	. .	0.08	4.0
	5	. .	. .	0.03	3.8
	7	. .	. .	0.0	4.0
	8	. .	. .	. .	4.8
	9	. .	. .	. .	6.3
3	Initial	8.0	3.5	0.5	6.0
	1	1.0	3.0	1.2	4.8
	2	1.2	3.0	1.4	5.7
	3	0.4	3.0	1.0	5.2
	4	0.0	0.0	0.0	5.0
	7*	. .	. .	. .	. .
4. M. B. sample lost	Initial	10.8	4.0	0.3	4.2
	1	1.8	3.0	0.3	4.5
	2	0.2	3.0	0.5	4.4
	3	0.2	3.0	0.1	3.4
	4	0.6	2.5	0.1	2.5
	5	0.0	1.0	0.1	4.3
	6	. .	0.0	0.05	3.6
	7	. .	0.0	0.0	2.7
5	Initial	9.2	3.0	0.6	5.2
	1	1.2	2.5	0.0	5.3
	2*	0.0	0.0	0.0	5.3
	3	0.0	0.0	0.0	5.7
	4	. .	. .	. .	4.6
	5	. .	. .	. .	3.9
	6	. .	. .	. .	6.1
	7	. .	. .	. .	6.9

It is evident that the free dissolved oxygen is absorbed first by the organic compounds present; then the nitrates disappear, and finally the nitrites; and the methylene blue is generally attacked just after the disappearance of the latter. Sometimes, as in samples 2 and 3, there is a considerable delay between the disappearance of nitrites and the decolorization of the methylene blue. This may probably occur when the organic matter and the available oxygen are about evenly balanced, so that after the exhaustion of the oxygen putrefactive changes are set up somewhat slowly. Whenever the methylene blue is decolorized it may be assumed that all oxygen as nitrates or nitrites has disappeared; and, *vice versa*, when the blue color is retained traces of these bodies are generally present. This condition is illustrated in Table IV for trickling filter effluents which did not decolorize after fourteen days at 37°. It will be noticed that these effluents contained a considerable

amount of organic matter as measured by "oxygen consumed," and that in all cases there was a marked reduction in oxygen content during incubation. Nitrites and nitrates remained, however, in all but three cases. This condition may be compared, for contrast, with that of the putrescible effluents in Table III and with four other sets of analyses quoted in Table V.

TABLE IV—OXYGEN AND OXIDIZABLE MATTER IN STABLE TRICKLING FILTER EFFLUENTS

(Parts per Million)

Initial Composition.				After Fourteen Days at 37°.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.	Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.			Nitrites.	Nitrates.	
6.8	4.0	5.5	5.6	0.0	0.0	0.0	3.2
2.8	3.0	5.5	8.4	0.3	3.5	1.5	7.6
5.2*	0.0	15.0	4.4	4.0	0.1	15.0	4.4
7.2	5.0	3.0	18.8	0.1	0.4	1.5	8.9
4.4	3.0	3.0	5.2	0.0	0.1	1.5	3.5
7.2	4.0	6.0	16.8	0.1	0.5	5.0	15.8
4.6	3.0	6.0	10.4	0.0	1.5	1.0	12.2
4.4	2.5	5.5	9.6	0.0	0.0	0.0	7.0
4.4	3.0	5.5	8.4	0.2	0.8	1.5	2.0
6.6	1.0	2.0	17.4	0.0	3.0	0.1	2.6
4.2	1.5	3.0	7.2	0.0	1.0	0.0	0.6
5.7	2.5	3.0	8.4	0.0	0.0	0.0	5.2
4.3	3.0	4.0	7.0	0.6	6.0	2.0	7.7

* Sand filter effluent.

TABLE V—OXYGEN AND OXIDIZABLE ORGANIC MATTER IN PUTRESCIBLE TRICKLING FILTER EFFLUENTS

(Parts per Million)

Initial Composition				Age, hours at 37°.	After Decolorization.			
Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.		Dissolved oxygen.	Nitrogen as		Oxygen consumed fifteen minutes cold.
	Nitrites.	Nitrates.				Nitrites.	Nitrates.	
4.3	2.0	3.0	24.4	24	0	0	1.5	25.2
1.1	2.5	3.0	14.0	12	0	0	0.0	14.0
5.8	1.5	5.0	15.6	40	0	0	0.0	16.0
3.8	1.5	5.0	8.8	120	0	0	0.0	2.8

An interesting practical question arises as to the relation of the methylene blue test to the original constitution of the effluent as determined by chemical analysis. If our methods were sufficiently precise we should be able to predict from determinations of organic matter and oxygen just what the result of their interaction will be. The condition of an effluent, as indicated by the relation of oxygen consumed to available oxygen, corresponds, however, only roughly to its putrescibility. Comparing Tables III, IV, and V, a general difference between

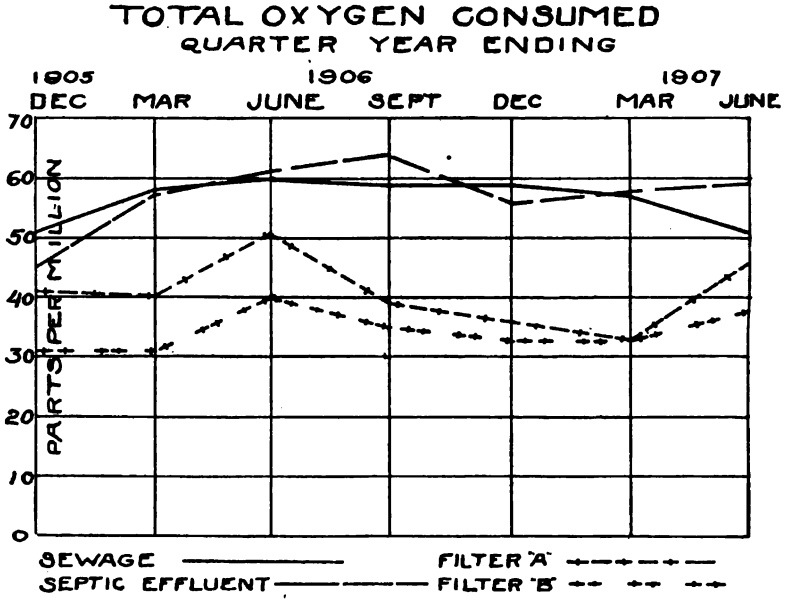

FIG. 11.—QUARTERLY VARIATIONS IN TOTAL "OXYGEN CONSUMED; SEWAGE AND EFFLUENTS

the stable and putrescible samples is apparent, the former, in Table IV, having on the whole a considerably higher ratio of available oxygen to oxygen consumed than the latter, as shown in Tables III and V. There are, however, many samples which contradict this general rule, and we have been unable on any basis of calculation to find a marked and constant difference in analysis between stable and putrescible samples. This has been still more forcibly brought out in our routine experiments. For a considerable period, as will be shown later on, one of our trickling beds gave stable effluents, while those from the other bed were putrefactive. Yet at the same time there were no

significant differences in the nitrogen and oxygen-consumed values of the two effluents. It is evident that certain factors affect the stability of an effluent which are not revealed by the ordinary methods of sanitary chemistry; and since this property of stability is precisely the point of greatest significance in sewage purification, the methylene blue test seems to us of supreme value in judging the work of trickling filters. We have therefore used it since February, 1906, in all our routine work, making daily tests of crude sewage, septic effluent, and trickling effluents before and after sedimentation.

Bacterial samples of sewage and effluents were taken three times a week from October, 1906, to April, 1907, and counts were made on litmus lactose gelatin at 20°. As a presumptive test for *B. coli* the bile medium of Jackson (1906) was used. As in Jackson's work, natural ox-bile was used, with the addition of 1 per cent. lactose; but we incubated our tubes for three days instead of two, which time he first recommended. The reason for this was that a series of sixty preliminary tests gave the results shown in Table VI, which indicated that forty-eight hours is too short a time to allow the development of all the gas-forming organisms present.

TABLE VI — POSITIVE REACTIONS WITH BILE MEDIUM AT VARIOUS PERIODS

Period of incubation.	Average positive results.	Average per cent. gas.
48 hours	77 per cent.	10
72 hours	92 per cent.	24
96 hours	95 per cent.	38

For the first three months of regular use, October to December, 1906, the bile test gave good results, yielding positive tests in crude sewage in one-millionth of a cubic centimeter. In January, however, either the number of colon bacilli greatly decreased or the bile obtained was antiseptic. In April *B. coli* could not be isolated by this method from one one-thousandth of a centimeter of sewage.

IV. COMPOSITION OF CRUDE SEWAGE

The sewage of the south Metropolitan district was made slightly weaker in October, 1904, by the diversion of the flow from its more

outlying areas into the new Peddock's Island high level sewer. Comparing the analyses of 1904–05 with those of 1903–04, a diminution of about 10 per cent. in the strength of the sewage was apparent. The analyses made since 1905 are not comparable with preceding ones, since both nitrogen and oxygen-consumed methods were changed at the beginning of the present investigation.

TABLE VII — COMPOSITION OF CRUDE SEWAGE

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	52	235	120	133	35	10.7	5.0	13.5	0.1	0.2	51	35	3.2
1906	1	43	245	110	125	46	8.9	6.4	13.1	0.0	0.4	58	46	5.6
1906	2	56	235	140	127	40	7.7	5.5	15.0	0.0	0.3	60	45	2.0
1906	3	72	314	160	149	60	9.8	6.9	15.0	0.1	0.0	59	44	0.2
1906	4	54	295	125	116	34	9.5	6.0	14.5	0.0	0.1	59	46	2.5
1907	1	42	320	115	149	46	9.5	6.0	12.5	0.1	0.2	57	45	6.5
1907	2	55	260	80	146	46	7.5	4.5	14.0	0.0	0.0	51	39	3.8
Average	. .	53	279	121	135	44	9.1	5.8	13.9	0.0	0.2	56	43	3.4

The average analysis of the crude sewage for each quarterly period from October, 1905, to June, 1907, is shown in Table VII. Most of the constituents were fairly constant throughout the whole period. The first quarter of the year is characterized by a marked increase of dissolved oxygen and a diminution of free ammonia, due to the inhibition of bacterial decompositions by low temperature. The second quarter of the year is marked by a decrease in organic nitrogen, due to the greater dilution of house sewage at that season with street washings and melted snow. At the same time, the free ammonia value rises with the rising temperature and more active bacterial decomposition. On the whole, the analyses indicate that the sewage used in these experiments was of about average strength for an American sewage. It is weaker than the sewages of many small Massachusetts cities where the proportion of house sewage is large. On the other hand, its organic content is slightly greater than that of the sewage of Columbus (Johnson, 1905). The "oxygen-consumed" value is 56 for Boston against 51 for Colum-

bus; the free ammonia value 13.9 against 11; and the Kjeldahl nitrogen figure 9.1 against 9. Columbus sewage contains only 79 parts of volatile suspended solids, while Boston sewage has 91, but shows 130 parts of fixed suspended solids against 44 parts for Boston.

The average bacterial content of the crude sewage from October, 1906, to April, 1907, inclusive, was 1,200,000 per cubic centimeter as

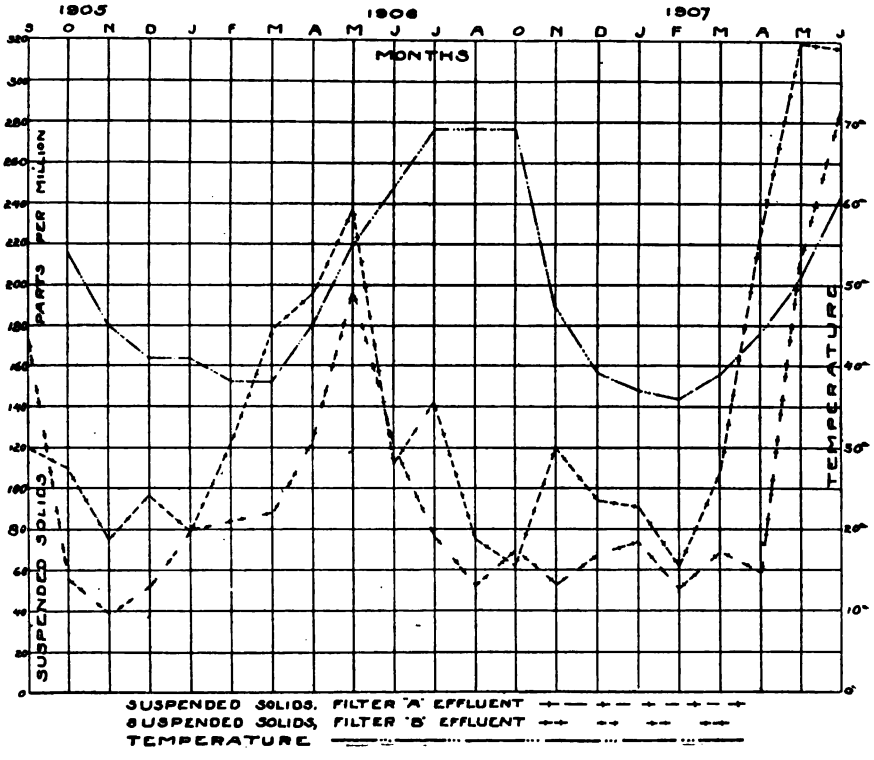

FIG. 12.—MONTHLY VARIATIONS IN TEMPERATURE AND SUSPENDED SOLIDS IN TRICKLING EFFLUENTS

determined by plating on litmus-lactose-gelatin at 20°. Of these, 20 per cent. were acid formers and 8 per cent. liquefiers. The average number of bacteria during the summer months would no doubt have been considerably higher, as shown by previous investigations (Winslow, 1905).

V. RESULTS OF SEPTIC TREATMENT

The septic system used in this investigation consisted, as already stated, of five tanks, each 6 feet long, 4 feet broad, and 3 feet deep.

These were connected by 2.5-inch pipes, and each contained a large baffle projecting from one corner nearly to the opposite corner, as shown in Figure 1. The path of a particle of liquid in each tank was about 10 feet long, and the action of all five tanks approximated that of a single tank 50 feet long and 3 feet wide.

Experiments were begun August 29, 1905, with all five tanks in series, but Nos. 2 and 3 were cut out October 19, 1905, and for one year three tanks alone were used. October 15, 1906, the two extra tanks were again placed in connection with the others. For the first year the total septic period was about seven hours, and for the last eight months it was twelve hours.

On the second day after the tanks were first started a scum formed, which gradually thickened so that after seven days it was sufficiently strong to retain gas bubbles. Masses of black sludge were observed rising to the top of the tank and floating. Conditions remained almost the same during the entire course of the investigation. The scum varied somewhat in amount from time to time, never attaining a thickness of over a quarter of an inch, and often entirely disappearing. Tanks Nos. 1, 4, and 5 operated for twenty months, and Tanks Nos. 2 and 3 for eight months, without any superficial indication of undue accumulation of solids.

There are two distinct processes involved in septic treatment — the removal of suspended solids by sedimentation and the liquefaction of the organic matter by bacterial action. The first of these processes is measured by the character of the effluent discharged, and Table VIII indicates what our septic tanks accomplished from this standpoint.

TABLE VIII — COMPOSITION OF SEPTIC EFFLUENT

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
					Total.	Fixed.	Total.	Solution.				Total.	Solution.
1905	4	52	175	70	86	16	7.9	5.0	14.3	. .	. .	45	36
1906	1	43	190	80	60	7	7.2	5.9	16.0	. .	. .	57	45
1906	2	58	215	93	105	21	6.3	3.7	18.6	0.1	0.1	61	43
1906	3	73	203	98	72	24	6.9	5.1	19.2	0.0	0.0	64	45
1906	4	53	220	85	52	15	7.5	5.5	17.0	0.0	0.0	56	46
1907	1	44	240	80	77	15	6.0	4.0	16.0	0.0	0.0	58	49
1907	2	55	250	105	118	31	3.5	1.0	21.5	0.0	0.0	59	42
Average	. .	54	213	87	81	18	6.5	4.3	17.5	0.0	0.0	57	44

Comparing the analyses of the septic effluent with those of the crude sewage (Table VII), it appears that the tank system removed 40 per cent. of the total suspended solids and 59 per cent. of the fixed suspended solids. There was a 28 per cent. decrease in the total organic nitrogen and, curiously enough, a 26 per cent. decrease in the organic nitrogen in solution. This latter point shows that the septic tank exercises a certain bacterial purification besides its primary sedimentary action. On the other hand, and, indeed, as a result of the decomposition of organic nitrogen, the tank effluent showed a 26 per cent. increase in free ammonia. "Oxygen-consumed" values were about the same in the effluent as in the crude sewage.

Some interesting points are brought out by a study of the quarterly analyses, which are plotted, for the more important constituents in Figures 5 to 11. Taking the organic matter first, it appears from Figure 7 that the removal of this type of material as a whole does not vary materially from season to season. Figure 8 shows, however, that the soluble organic nitrogen is much more strikingly reduced during the second and third quarters of the year than at other times. At the same season, as appears from Figure 9, the production of free ammonia in the septic tank increases rapidly. These phenomena are both, of course, correlated with the increased bacterial action which follows the setting in of warm weather. The same close relation between

septic action and temperature has been shown by Kinnicutt and Eddy (1902), in their study of the gases formed in a closed septic tank. This point is of much importance in plans for the use of septic tanks under varying climatic conditions, as Fowler has pointed out. In India septic tanks work to perfection, while in Russia they are unsatisfactory (Fowler, 1907).

FIG. 13.—VIEW OF GRAVITY DISTRIBUTOR IN OPERATION

Turning to Figures 5 and 6, it appears that the septic tank is least efficient in the removal of suspended solids just at the time when its period of greatest biological activity begins; that is, in the second quarter of the year. This we explain by the active fermentation which manifests itself in the lifting of masses of sludge from the bottom of the tank and the general stirring up of its contents, and naturally leads to the discharge in the effluent of a larger proportion of suspended matter than at times of comparative rest.

Figures 10 and 11, showing the relations for carbonaceous matter, as indicated by the "oxygen-consumed" test, are somewhat surprising from the close parallelism which they indicate between the sewage and the septic effluent. Matter of this class was apparently not appreciably decomposed and scarcely affected by sedimentation. The alternative to this conclusion is to suppose an actual removal of carbonaceous matter, balanced by the production of new reducing bodies. It is difficult to suppose that such a process would yield the uniform results indicated by Figure 11. English septic tanks show, as a rule, a distinct loss of "oxygen consumed" (Winslow and Phelps, 1906*a*).

We believe that differences in results of this sort at different places are to be explained in part, at least, by the different methods in use in determining the oxygen-consumed value. The more vigorous the oxidizing action of the permanganate the more nearly the results approach the true total carbon values. Changes in the nature of the carbonaceous matter, which do not affect its total amount, are quite obscured by analytical procedures like the present standard method, involving a long period (half an hour) of boiling. The less intense English cold methods, on the other hand, give results which are markedly dependent on the nature as well as the amount of the carbonaceous matter. They are therefore extremely valuable in studying those slight chemical changes which accompany sewage purification. It is even possible to detect a difference between the results of the present standard method, involving a half-hour boiling, and the older Massachusetts method of two minutes' boiling, used in this laboratory two years ago. By the latter method our six septic tanks showed an average removal during two years of 14 per cent. of the total "oxygen consumed," as compared with no removal whatever in the present series as determined by the present standard method.

One notable point brought out by these diagrams is the fact that the change from three septic tanks to five, made in October, 1906, did not appreciably alter the character of the effluent. Judged by the analytical results, seven hours' storage is apparently sufficient to effect all the septic changes which will take place in this particular sewage.

The extent to which it accumulates sludge is quite as important a point in the working of a septic tank as the character of its effluent. This point was studied by the method used in our previous investigations. On three occasions — June 30, 1906, when the tanks had run eight months; July 1, 1907, after they had run twenty months;

and August 3, 1907, after they had stood without the addition of fresh sewage for one month — the inlets and outlets of all the tanks were closed and the contents of each tank, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table IX. The analyses refer to the total liquid and solid contents

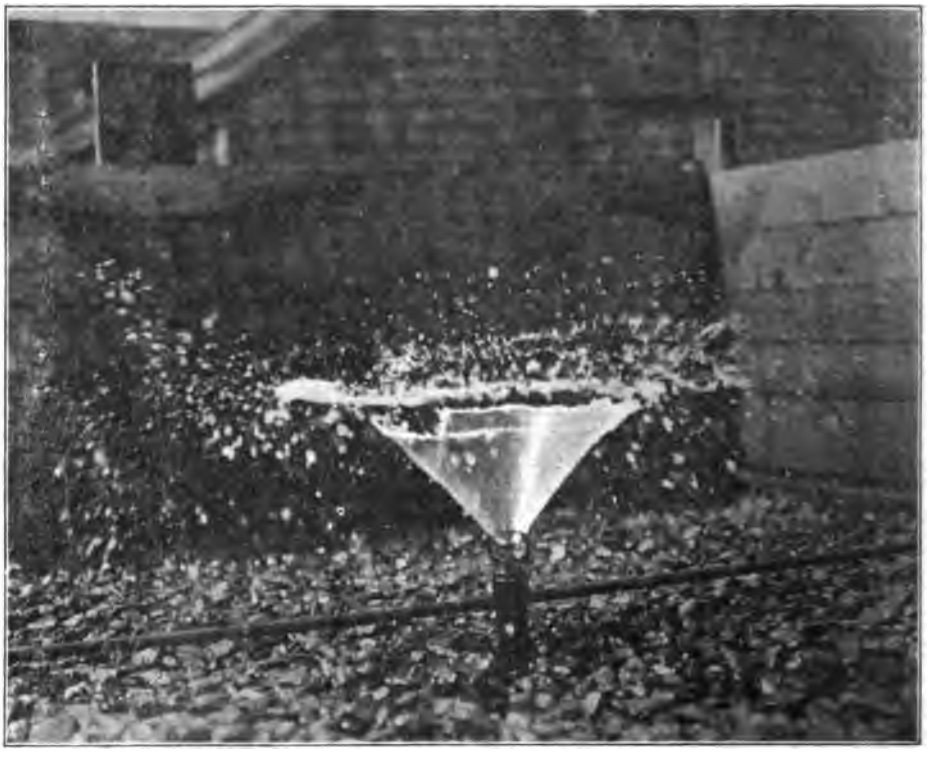

FIG. 14.— VIEW OF COLUMBUS SPRINKLER IN OPERATION

of each tank at the time its operation ceased, a suspension containing about 98 per cent. of water. The sludge was estimated by allowing the mixed tank contents to settle in a cylindrical vessel for twenty-four hours and observing the relation between the thick sediment produced and the clear supernatant liquid. The thickness of the sludge (which as measured by this method includes the scum) was about 4 inches after the first year of operation, and averaged nearly a foot at the end of the investigation.

TABLE IX — ANALYSES OF SEPTIC TANK CONTENTS, INCLUDING SLUDGE AND SCUM

(Parts per Million)

Date.	Tank.	Liquid contentr.	Depth of sludge.	Solids.		Organic nitrogen.	Oxygen consumed.
				Total.	Volatile.		
		Gallons.	Feet.				
June, 1906	1	518	0.3	7,000	3,900	. .	770
	4	498	0.2	4,400	2,200	. .	520
	5	444	0.3	9,900	4,500	. .	1,200
July, 1907	1	450	0.9	. .	. .	1,000	9,000
	2	468	1.1	. .	. .	1,400	9,900
	3	468	0.8	. .	. .	860	7,300
	4	486	0.9	. .	. .	1,100	9,400
	5	495	0.5	. .	. .	610	5,200
August, 1907	1	450	0.7	25,000	4,000	380	4,900
	2	468	0.5	18,000	3,200	290	3,700
	3	468	1.1	46,000	9,700	590	7,400
	4	486	1.1	38,000	3,000	560	7,000
	5	495	1.2	44,000	7,700	540	7,000

It appears from Table IX that the differences between the individual tanks at a given time were only such as would be expected from sampling errors with a thick organic suspension. The composition of the liquid in the three (or five) tanks was approximately the same at a given time, and the system may therefore be considered as a whole.

Comparing the 1906 analyses with those made at the end of the twenty-one months, it is evident that the amount of fixed solids in the tanks increased considerably during the course of the experiments. The same thing is true of oxygen consumed, and in each case the increase is more than proportional to the time of operation. This is, perhaps, partly due to the fact that during the first year the system was operated with a seven-hour period, and during the second year with a twelve-hour period. Our previous investigations have shown that long storage periods are associated with the undue accumulation of sludge (Winslow and Phelps, 1906 *a*), and similar observations have been made at Lawrence (Massachusetts, 1901).

Over-septic sewage may inhibit the action of the liquefying organisms, or there may occur a secondary precipitation of inorganic reducing

bodies, iron compounds, for example. Too much aging seems, at any rate, to be associated with an increase in fixed solids and in oxygen consumed. The same phenomenon occurs when sludge is stored in a bottle in the laboratory. Table X shows the results of successive analyses of two samples of septic sludge so tested in July, 1906. The mere aging of the septic system as a whole might tend to increase such reactions during the second year. At London and at Leeds a gradual deterioration of septic effluents was noted with the increasing age of the tanks (Winslow and Phelps, 1906 *a*).

TABLE X — SEPTIC SLUDGE BEFORE AND AFTER STORAGE
(Parts per Million)

Storage, days.	Fixed solids.	Volatile solids.	Oxygen consumed.
0	33,600	35,880	7,040
2	43,500	36,400	9,960
5	52,560	35,840	10,960
0	30,900	31,400	7,360
2	34,200	26,300	8,340

The effect of a month's rest of the septic tanks is shown by a comparison of the analyses for July and August, 1907. The total amount of sludge did not change materially, but the oxygen-consumed value was slightly reduced and the organic nitrogen dropped more than 50 per cent. Suspended solids were still, however, very high. It is evident that after nearly two years of operation our septic system was approaching the limit of its capacity. With a foot of sludge in the bottom of the tanks, equal to 35 per cent. of the tank capacity, the effluent might soon have been expected to deteriorate. It is probable, therefore, that septic tanks operating with Boston sewage would require emptying once in two or three years.

A somewhat clearer idea of the actual work of the septic tanks may be gained by reducing the analytical data to the actual quantities they represent. During the twenty-one months of the investigation 2,490,000 gallons of sewage passed through the septic system. This volume of sewage carried 2,790 pounds of suspended solids (of which 1,880 pounds were volatile) and 188 pounds of organic nitrogen. The effluent leaving the tanks bore 1,670 pounds of suspended solids (of which 1,300 pounds were volatile) and 134 pounds of organic nitrogen. The septic

system, therefore, removed 1,120 pounds of solid matter (580 pounds volatile and 540 pounds fixed) and fifty-four pounds of organic nitrogen.

TABLE XI — STORAGE AND DECOMPOSITION OF ORGANIC MATTER IN SEPTIC TANKS

Percentages of Sewage Value

	Suspended Solids.		Organic nitrogen.
	Fixed.	Volatile.	
Sewage	100	100	100
Septic effluent	41	69	71
Removed by tank	59	31	29
Stored in tank	62	6	4
Decomposed in tanks	3*	25	25

* Precipitated.

There were left stored in the tanks, after twenty-one months of operation and one month's rest, 675 pounds of solids (of which 109 pounds were volatile) and eight pounds of organic nitrogen. Four hundred and seventy-one pounds of volatile solids and forty-six pounds of organic nitrogen had, therefore, been decomposed in the tanks, while the fixed solids had been increased by twenty-six pounds — additional evidence of the precipitation of inorganic solids previously alluded to. These results are shown in the form of percentages in Table XI, where their relations may be somewhat more easily grasped.

On the whole, it appears that the septic tank will remove nearly two-thirds of the fixed suspended solids from Boston sewage and about one-third of the organic matter, as measured by suspended volatile solids or organic nitrogen. Of the organic matter in the sludge thus removed four-fifths is decomposed. The fixed solids, on the other hand, accumulate to such an extent as to require the cleaning of the tanks once in two or three years. A seven-hour period gives as good an effluent as a twelve-hour one, and probably produces a less accumulation of sludge. All these results harmonize very closely with those obtained in the previous experiments of 1903–05 (Winslow and Phelps, 1906 *a*).

The average bacterial content of the septic effluent for the eight months, October, 1906, to April, 1907, was 750,000, a reduction of

38 per cent. as compared with the crude sewage. The proportion of acid formers and liquefiers was about the same as in the sewage, 16 per cent. of the former and 8 per cent. of the latter. The results of the bile test for *B. coli* were somewhat erratic. In October and November the number of gas formers was apparently increased by passage through the septic tanks; in October 19 per cent. of the tests in one-millionth of a cubic centimeter were positive in the sewage and 56 per cent. were positive in the septic effluent; in November 9 per cent. of the tests were positive in the sewage and 38 per cent. in the septic effluent. From December to April negative results were consistently obtained in one-millionth of a cubic centimeter. The crude sewage showed 19 per cent. of positive results in December, 11 per cent. in January, 12 per cent. in February, and none in March and April.

VI. Results of Trickling Filtration

The general construction of the two trickling filters has been already described and is shown in Figures 1, 2, and 3. Both were 8 feet deep, and the surface of each was a square, approximately 10 feet on a side. Both were filled with 1½ to 2 inch broken stone. Filter A received crude sewage and filter B septic effluent.

The exact area of filter A was 98.47 square feet, or .00226 acre; of filter B, 94.57 square feet, or .00217 acre. The rate on each bed during operation was 200 gallons per hour for twenty-two hours each day, a gross rate of approximately 2,000,000 gallons per acre per day. During the summer months the plant was shut down on Sundays, while in winter it was run continuously to obviate the chilling of the bacteria in the empty bed. In September, 1906, the whole plant was shut down for two weeks. Careful records of operating time show that the filters were operated for 12,450 hours in the ninety-one weeks from October 1, 1905, to July 1, 1907. This means an average operation of 137 hours a week, or 5.7 days. The total amount of sewage applied to each bed was 2,490,000 gallons — an average of 3,900 gallons a day. The net rate of operation was, therefore, 1,730,000 gallons per acre per day for filter A, and 1,800,000 gallons per acre per day for filter B.

Each filter was at first equipped (August 21, 1905) with four gravity distributors — copper disks, 3 inches in diameter, with a 6-inch radius of curvature. Those on the septic side corroded badly, and on November 1 four new disks were substituted on each side to test the durability

of various alloys. Pure aluminum proved as bad as copper, but three alloys — brass, bronze, and a nickel bronze — gave no indications of corrosion. No trouble was experienced in any case on the crude sewage filter.

The winter of 1905–06 was a fairly mild one, as may be seen by reference to Table XII, in which the maximum and minimum temperatures for the three winter months are tabulated from the published data of the United States Weather Bureau. The "normal" December temperature at Boston for different days of the month varies between 27° and 35° F., the normal January temperature between 24° and 31° F., the normal February temperature between 23° and 31° F. Ice first formed on the filters November 11, 1905, and by January 10 all the sprinklers were covered with mantles of ice — tubes about 1 foot in inside diameter, continuous from the box above the sprinkler to the surface of the bed. Inside this mantle all the sewage was distributed, and the areas between the four 1-foot circles were covered with 6 to 8 inches of ice.

In August, 1906, a slight pooling of sewage was observed on the beds, particularly on filter A. On digging into the beds it appeared that just under the four sprinklers the stones were clogged with black sludge. This layer was turned over with a pick to about a foot in depth on filter A, but no material was removed. It was evident, however, that the four sprinkling disks, each operating at a rate of .8 gallon per minute, were not distributing satisfactorily; and this experience illustrates the importance of proper distribution in trickling filters. In the middle of November changes were made in the distributing system as previously described. Filter A was equipped with a single gravity disk just like the four previously used, and filter B was equipped with a pressure nozzle of the Columbus type, and dosed intermittently from a siphon tank. The new distributors in normal operation are shown in Figures 13 and 14.

After this change no difficulty was experienced in securing a satisfactory working of the filters at all times. There was no tendency to surface pooling; analytical results were good, and, as will be seen later, there was no important accumulation of material in the beds. The winter of 1906–07 was much more severe than the previous one, and more severe than the average. Minimum temperatures fell below 5° F. on fifteen different days. On twelve days the maximum temperature was under 20° F.; for five successive days in January and

TABLE XII — MAXIMUM AND MINIMUM DAILY TEMPERATURES FOR WINTER MONTHS

(Degrees Fahrenheit)

United States Weather Bureau

Day.	December, 1905.		January, 1906.		February, 1906.		December, 1906.		January, 1907.		February, 1907.	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	33	12	41	32	47	34	47	30	50	39	36	21
2	54	26	33	26	38	6	30	12	30	12	42	30
3	61	39	35	22	18	—1	34	11	40	30	41	17
4	39	28	58	35	42	16	16	4	57	38	20	14
5	35	22	43	37	43	15	36	13	42	35	21	10
6	38	25	41	31	20	3	54	29	45	34	20	8
7	46	35	34	27	23	9	48	4	58	40	24	6
8	55	36	25	16	30	9	14	1	41	37	30	16
9	39	36	28	10	36	28	18	13	43	17	26	14
10	37	18	26	9	37	23	40	18	36	12	39	22
11	32	15	35	15	25	12	32	14	45	35	37	7
12	28	20	54	34	38	24	25	9	38	21	17	2
13	44	20	37	33	40	34	35	25	34	22	27	1
14	36	13	37	25	40	36	34	29	34	26	52	26
15	23	8	35	24	36	13	53	33	29	16	37	28
16	32	20	52	33	33	10	49	35	16	1	42	26
17	37	19	42	32	34	18	37	33	9	—4	39	20
18	51	25	44	31	37	27	36	12	35	9	26	16
19	44	33	38	25	45	32	30	10	42	29	37	14
20	47	36	46	24	53	32	44	24	58	34	36	28
21	51	36	68	46	63	42	45	36	34	18	38	14
22	50	40	63	48	48	34	41	33	34	17	19	4
23	41	37	68	53	38	28	34	15	17	—2	13	—2
24	38	28	60	25	48	31	24	12	8	—7	23	0
25	37	24	26	19	42	31	27	20	16	4	34	11
26	41	26	34	20	48	32	31	20	22	13	22	4
27	51	32	48	29	35	19	43	25	19	10	24	6
28	55	36	46	35	20	9	40	34	28	13	26	2
29	58	38	36	15	. .	. .	47	36	29	12	. .	. .
30	45	37	48	25	. .	. .	41	38	32	11	. .	. .
31	44	35	56	37	. .	. .	53	38	27	6	. .	. .

for four successive days in February the maximum temperature was under 25° F. (see Table XII). Yet ice and snow collected only at the outer edge and corners of the filters, leaving the main part of their surface clear. The condition of the beds at their worst is shown in Figures 15 and 16. The Columbus nozzle kept open a slightly larger circle, but built up a higher wall of ice at the periphery, owing to its intermittent action. It is interesting to note in Figure 16 the extra ice formation at the two points where the knife-edge supports of the spraying nozzle slightly diminish the flow of sewage. Both methods of distribution, however, worked excellently under the severe winter conditions, and the effluents remained well up to standard.

The analyses of the effluents from filters A and B are tabulated by quarters in Tables XIII and XIV. Regular analyses were not begun till October, 1905, but special analyses during the first month of operation showed that the beds rapidly attained a normal activity. Three parts per million of nitrates were found after a week's operation in the effluent of filter A and five parts in the effluent of filter B. The effluents were extremely turbid at first, and after a month still showed more oxygen consumed than the sewage. By the middle of October, after six weeks of operation, turbidity and organic matter decreased, and the beds assumed their normal operation.

TABLE XIII — COMPOSITION OF EFFLUENT FROM FILTER A

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	47	155	85	104	27	7.6	2.9	11.6	1.0	3.8	41	24	7.6
1906	1	39	170	110	130	51	6.0	3.9	12.1	0.5	4.0	40	27	9.3
1906	2	53	300	205	186	88	7.6	3.4	13.2	1.8	4.3	51	29	4.7
1906	3	69	183	108	104	45	8.1	3.6	9.3	2.5	3.9	39	24	4.9
1906	4	52	185	155	88	40	6.1	2.9	9.5	0.6	4.5	36	25	7.7
1907	1	39	210	115	87	28	4.9	2.3	8.9	0.3	5.4	33	22	11.2
1907	2	51	270	170	269	130	8.2	2.7	8.5	0.7	5.2	46	26	10.2
Average	. .	50	200	136	138	58	7.1	3.1	10.4	1.1	4.4	41	25	7.9

TABLE XIV — COMPOSITION OF EFFLUENT FROM FILTER B

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Temperature F.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.		Oxygen dissolved.
					Total.	Fixed.	Total.	Solution.				Total.	Solution.	
1905	4	45	90	45	72	20	5.6	2.7	12.0	0.9	4.1	31	24	8.0
1906	1	39	130	60	83	38	4.9	3.5	14.3	0.1	4.3	31	22	9.3
1906	2	62	215	140	155	85	4.9	2.3	15.3	1.2	4.4	40	23	4.4
1906	3	60	128	66	62	28	6.4	3.4	11.3	3.3	4.5	35	26	5.4
1906	4	52	120	65	50	22	6.0	2.0	11.5	1.2	4.6	33	26	7.6
1907	1	37	145	65	61	22	3.7	1.8	10.7	0.7	5.0	33	27	10.2
1907	2	52	200	105	198	46	3.2	1.1	13.3	1.0	5.7	38	26	8.2
Average	. .	51	147	78	96	37	5.8	2.4	12.6	1.2	4.7	34	25	7.6

From the Tables VII, VIII, XIII, and XIV and from Figures 5 and 6 it appears that the total amount of suspended solids discharged by each filter was slightly in excess of that received by it. An average value of 135 parts per million in the crude sewage was increased to 138 in filter A, and a value of 81 parts in the septic effluent was increased to 96 parts in filter B. A very interesting seasonal curve is indicated, however. The amount of solid material was less in the effluent than in the applied sewage except in the second quarter of the year. In some quarters, filter A effected a 40 per cent. reduction in suspended solids. In the second quarter of each year, there was an enormous increase of suspended solids in the effluent to a point in excess of the amount in the applied sewage. This means, of course, that the suspended solids of the sewage are ordinarily held on the bacterial films which cover the stones, while during the second quarter the accumulated material is washed out again into the effluent. We suspected at first that spring rains might account for this phenomenon, but a more careful study showed that the increase of solids in the effluent did not correspond to heavy rainfall, and it appeared from calculation that this factor could not be of great importance. Two inches of rain falling in an hour would double the rate on a 2,000,000-gallon per acre filter, but such a storm rarely occurs in the latitude of Boston. Monthly values for suspended solids and temperature,

which have been tabulated in Table XV, show, on the other hand, a suggestive correlation.

TABLE XV — SUSPENDED SOLIDS AND TEMPERATURE OF TRICKLING EFFLUENTS

Month.	Filter A.		Filter B.	
	Temperature F.	Solids.	Temperature F.	Solids.
September, 1905	..	120	..	173
October	55	110	54	56
November	46	75	45	39
December	41	97	41	52
January, 1906	40	79	41	80
February	39	122	38	..
March	37	178	38	88
April	46	195	45	124
May	55	237	55	197
June	61	112	62	121
July	69	142	69	76
August	70	75	69	52
September	..	..	..	..
October	69	62	69	70
November	48	120	47	58
December	40	94	39	68
January, 1907	39	91	37	74
February	37	62	36	51
March	40	107	39	69
April	44	223	44	59
May	51	319	51	213
June	60	316	61	288

The figures in Table XV are tabulated in graphic form in Figure 12. Both filter effluents show a progressive decrease of solid material from May onward till the early spring, when a sudden increase occurs. The trickling filter evidently has its own definite yearly life cycle, and upon this, rather than upon the applied solids, do the solids in the effluent depend. It seems probable that the bacterial films upon the stones absorb or otherwise hold the solid material which reaches them until by this process of accretion and their own multiplication the mass becomes heavy enough to break away With Boston sewage a year's supply of solids can thus be stored; but

the bacterial multiplication set up, when warm weather begins, serves to upset the equilibrium of the bed, and the solids collected during the preceding ten months are discharged. It will be noted, however, by reference to Figure 12, that solids began to increase in A effluent before the onset of warm weather. In each year its rise preceded that of B by two months. This bed received a considerably larger amount of suspended solids than filter B, and it seems probable that the mere accumulation of material began to cause the detachment of zoöglœa before the spring increase in growth occurred. There is at any rate abundant evidence here that the trickling bed automatically frees itself from suspended solids after accumulation has taken place to a certain extent. This phenomenon will militate strongly against permanent clogging of the trickling bed.

In this connection the nature of the suspended matter is also of significance. In filter A the volatile suspended solids were reduced, on the average, from 91 parts to 80 parts, while fixed suspended solids were increased from 44 parts to 58; in filter B volatile suspended solids fell from 63 parts to 59, while fixed suspended solids rose from 18 parts to 37. The larger increase of fixed suspended solids in the septic side is probably due in part to the precipitation of iron sulphide, a deposit of which was later found on the bottom of the bed. In filter A, however, there is no evidence of such a reaction, and the figures seem to indicate a real conversion of organic matter into some insoluble mineral form. It is apparent to the eye that the suspended matter in the effluent of a trickling filter is quite different from that which goes on at the top. It is in much larger particles, as may be seen by the eye, and it settles much more easily. It is for this reason that the turbidity of both effluents was considerably reduced (200 for filter A against 279 in the sewage, and 147 for filter B against 213 in the septic effluent). Microscopic examination by the Sedgwick-Rafter method (Whipple, 1905), carried out under our direction by Mr. H. S. Spaulding, showed that the finely divided particles of suspended matter, of a size less than five standard units, were reduced from 300,000 per cubic centimeter in crude sewage to 28,000 in trickling effluent, while the larger particles, and particularly the macroscopic particles, were increased in numbers. In appearance the material in the trickling effluent is structureless and somewhat flocculent, resembling the amorphous matter so frequently found in water analysis. In its formation the original suspended matter applied to the filter has evidently been

thoroughly worked over. It is somewhat surprising, in view of these facts, that the sum of the suspended matter applied and discharged should tally so nearly.

In organic content both effluents show a marked reduction. The purification per cent., as measured for each of the principal constituents, is shown in Table XVI. The results are remarkably close, with the exception of the total "oxygen-consumed" value for the septic side, which exception may be accounted for by the precipitation of iron compounds already alluded to. In all other cases there was a reduction of about 25 per cent. in total organic matter and 40 per cent. in organic matter in solution.

TABLE XVI — PURIFICATION EFFECTED BY TRICKLING BEDS

Percentages

	Organic Nitrogen.		Free ammonia.	Oxygen Consumed.	
	Total.	In solution.		Total.	In solution.
Filter A	22	47	25	27	42
Filter B	23	44	28	40	43

Figures 7 to 11 show that in general the organic matter in the effluent does not exhibit any marked seasonal variations. There is one striking exception, however, to this rule. From Figure 11 it appears that the total "oxygen-consumed" value rose inordinately in the second quarter of each year. This is evidently correlated with the increased discharge of suspended solids at the same time, and it is clear, since no corresponding increase in nitrogen occurred, that the organic matter which then appeared in the effluent was chiefly carbonaceous. This fact strengthens the possibility that the material discharged from the trickling bed is largely bacterial zoöglœa.

Two other points only demand special mention, the dissolved oxygen in the effluents and their content of mineral nitrogen. Dissolved oxygen was at all times present in both effluents in considerable amounts. It was highest in the first quarter of each year, when bacterial decompositions were checked by the cold, and it was distinctly higher during the second year than the first, owing to the better system of distribution. The values for nitrites and nitrates are plotted in Figure 17. Nitrites were at a maximum in both effluents in the autumn of 1906; since the 1907 curve stops at July 1 it is uncer-

tain whether the same phenomena would have been repeated in that year. It is apparent, however, that the process of nitrite formation is markedly favored by high temperatures. The curve for nitrates, on the other hand, shows a pretty steady increase from the beginning to the end of the experiments, and indicates a progressive improvement in nitrifying power. Taking the sum of the organic and ammoniacal nitrogen in applied liquid and effluent, in comparison with the sum of the nitrates and nitrites, it appears that filter A received 23 parts of unoxidized nitrogen (organic and ammoniacal) and discharged 17.5 parts of unoxidized and 5.5 parts of oxidized nitrogen, nitrates, and nitrites. Filter B received 24 parts of unoxidized nitrogen and discharged 17.6 parts of unoxidized and 5.9 parts of oxidized nitrogen. There is, therefore, no evidence of appreciable storage or loss of nitrogen in filter A, and filter B shows a difference of only half a part. Table XVI shows that the per cent. purification effected by filters A and B was approximately equal as regards organic matter. Since the liquid applied to filter B had undergone preliminary treatment in the septic tank its effluent was, of course, actually superior to that of filter A. It contained only 96 parts of suspended solids against 138 parts for filter A, 5 parts of organic nitrogen against 7.1 parts, and 34 parts of oxygen consumed against 41 parts. Its free ammonia content was, however, higher, making the sum of the ammonia and organic nitrogen practically the same in both cases (17.6 and 17.5). The only significant difference between the effluents lay, therefore, in the fact that filter A discharged more suspended solids, both fixed and volatile, than filter B.

These results of chemical analysis are of considerable theoretical interest as throwing light on the processes which go on in the trickling bed; but, as we have pointed out already, they do not adequately measure the practical value of the purification effected. Neither the analyses of the effluents nor the figures for purification per cent. would by themselves suggest that our beds were doing satisfactory work. The methylene blue test, on the other hand, showed that the effluents of both filters were for the most part stable, and it is this test which furnishes the true criterion of their quality.

The methylene blue test was made on each effluent daily from February, 1906, to the end of the experiments, and the results are plotted in Figures 18-*A* and 18-*B*. The black blocks indicate the periods of decolorization by days up to fourteen days, the maximum time of observation.

During the cold months of February and March, 1906, results were notably irregular for both effluents. The sample collected on one day might prove stable, while that of the next would decolorize in two or three days.

With the beginning of warm weather, which favors harmful putrefactive changes, both before and during the process of filtration, both

FIG. 15.—VIEW OF GRAVITY DISTRIBUTOR UNDER SEVERE WINTER CONDITIONS

effluents further deteriorated. Filter B recovered about the end of May, and throughout the summer its effluent was generally stable. Filter A remained in poor condition until September, and was uncertain in its action for two months longer. The contrast between these beds brings out very clearly the great delicacy of the methylene blue method of testing effluents. The analyses for the third quarter of 1906 in Tables XIII and XIV show, indeed, a slight superiority for

filter B, but it is far too slight to lead to the conclusion that at this time one of the filters was practically a success and the other practically a failure.

With the installation of the new sprinklers in November, 1906, a decided change was manifest. After the middle of December, by which time the filter organism had become adjusted to its new conditions, both effluents were almost constantly stable. Occasionally, particularly during the winter months, and with filter A, a putrescible effluent was obtained, but this was rare. From December 15, 1906, to June 28, 1907, 156 samples of each effluent were examined by the methylene blue test. On the crude sewage side 127 samples were stable for fourteen days, nineteen more were stable for over four days, and ten only became decolorized in four days or less at 20°. The effluent of filter B showed 129 samples stable for fourteen days, sixteen more stable for more than four days, and eleven which were decolorized in four days or less. In other words, on 93 per cent. of the days both effluents were of sufficiently good quality to retain free oxygen for over four days.

Three conditions appear mainly responsible for imperfect operation when it did occur. In the first place, excessively low temperatures evidently impair the activity of the purifying organisms. The break in the curve for both filters on February 28, 1906 (see Fig. 18-*A*), was coincident with a fall from 19° to 9° F. The bad results obtained during the first week of December, 1906, accompanied minimum temperatures of 4° to 9° F. (Fig. 18-*B*). After the new distributing apparatus was in good working order, however, this effect of cold weather was only slight. Thus the severe weather of January 16 to 18, January 23 to 25, February 11 to 13, and February 22 to 24, 1907 (see Table XII), shows only slight effects in Figure 18-*B*.

The second factor affecting the stability of the effluents was the spring discharge of suspended solids. This phenomenon in April, 1906, evidently caused the bad break in the quality of the effluents manifest at that time and indicated in Figure 18-*A*. The interesting point in this connection is, however, that the much larger amount of suspended solids washed out in the second quarter of 1907 (see Fig. 5) produced no corresponding increase in putrescibility; that is, with proper distribution the solids discharged are so well oxidized or otherwise rendered stable that they do not interfere with the stability of the effluent.

The third factor which affects the character of the effluent

unfavorably is irregularity in the operation of the filter. In Figure 18-*A* the sample taken after a day's rest (the Monday sample) appears again and again the worst of the week, and during the second year the only serious interference with the work of filter B followed the three days' rest of May 18 to 21. This action was always most marked in cold weather. Whether it is due to the injury of the bacteria in the filter by changed conditions or to the detachment of

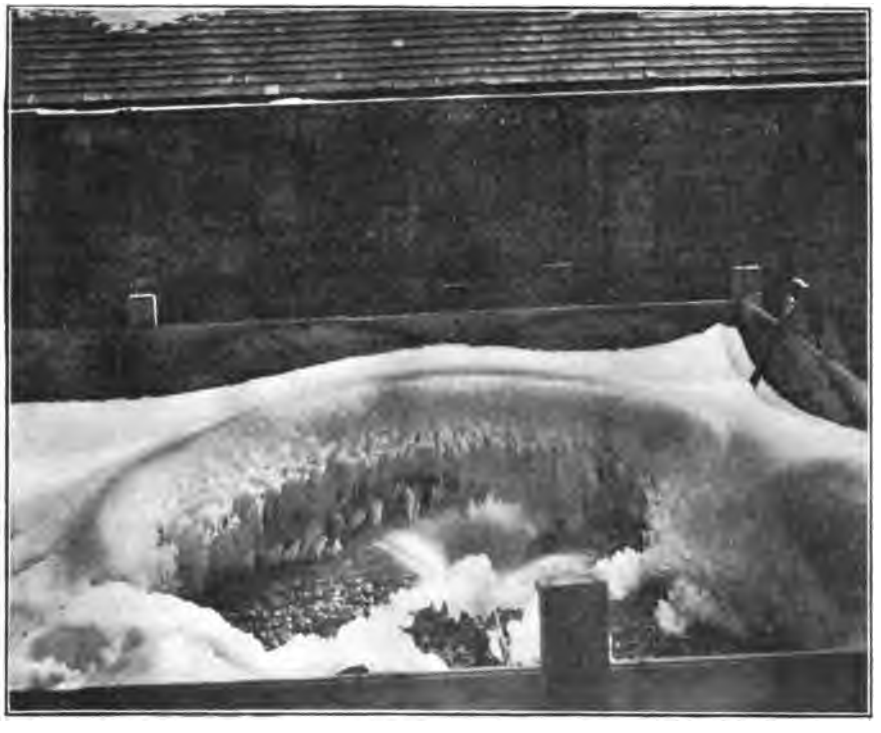

FIG. 16.—VIEW OF COLUMBUS SPRINKLER UNDER SEVERE WINTER CONDITIONS

dried zoöglœa is uncertain. It is clear, however, that resting the filter is detrimental to the effluent, and the results for the second quarter of 1907 show that the necessary removal of accumulated material can be accomplished in a natural way without such unfortunate results. We are therefore led to conclude that extended periods of rest for the recuperation of the bed and drying up of the accumulated organic material are not only unnecessary, but actually detrimental, and that the operation of a trickling filter should be made as constant and uniform as possible.

TABLE XVII—STABILITY OF TRICKLING FILTER EFFLUENTS

Percentage of Samples Decolorized at Each Specified Period

"A" EFFLUENT.										Total samples.
Days		0–2	2–4	4–6	6–8	8–10	10–12	12–14	14+	
Year.	Quarter.									
1906	1	40.5	18.9	2.7	5.4	8.1	0.0	0.0	24.4	37
1906	2	42.6	26.0	20.6	2.7	2.7	2.7	0.0	2.7	73
1906	3	23.7	38.9	15.3	5.1	6.8	0.0	0.0	10.2	59
1906	4 *a*	2.4	9.5	14.3	4.8	9.5	7.1	2.4	50.0	42
1906	4 *b*	2.9	11.4	2.9	8.6	11.4	2.9	8.6	51.3	35
1907	1	2.7	4.1	6.7	2.7	2.7	4.1	8.1	68.9	74
1907	2	4.4	2.9	1.5	0.0	1.5	2.9	1.5	85.3	68

"B" EFFLUENT.										Total samples.
Days		0–2	2–4	4–6	6–8	8–10	10–12	12–14	14+	
Year.	Quarter.									
1906	1	38.8	16.7	5.5	8.4	8.4	5.5	2.8	13.9	36
1906	2	16.9	22.6	26.7	2.8	9.8	1.4	1.4	18.4	71
1906	3	11.9	15.3	10.2	5.1	0.0	0.0	3.4	54.1	59
1906	4 *a*	2.3	0.0	0.0	0.0	4.5	2.3	2.3	88.6	44
1906	4 *b*	14.6	20.4	14.6	11.6	2.8	5.8	5.8	24.4	34
1907	1	4.0	4.0	0.0	2.7	1.3	0.0	4.0	84.0	75
1907	2	5.8	0.0	5.8	5.8	1.4	0.0	0.0	81.2	69

The results of the methylene blue test for each quarter are indicated in Table XVII, samples being divided by their decolorization periods into eight classes, those which decolorized inside of two days, between two and four days, between four and six days, etc., the last class including those which were still stable after fourteen days. The fourth quarter of 1906 is divided so as to differentiate the samples collected before and after the change in the distribution system.

The table shows in each case poor results with the old system of distributors. Filter B treating septic effluent was much better than filter A, however, and showed a steady improvement during this period. When the Columbus sprinkler was installed on filter B a serious temporary derangement followed; but by January, 1907, the filter had become adjusted to the new conditions, and for the last six months yielded effluents, 93 per cent. of which were stable for four days and over 80 per cent. stable for fourteen days. The substitution of a single

gravity distributor instead of four on filter A was followed by a steady improvement. Ninety-three per cent. of the samples of A effluent have been stable for four days since January, 1907, and the percentage stable for fourteen days rose from nearly 70 per cent. in the first quarter of the year to 85 per cent. in the second.

Bacterial examinations showed an average of 200,000 bacteria per cubic centimeter in the effluent of filter A and 180,000 in the effluent of filter B. The figures correspond to removals of 83 per cent. and 76 per cent., respectively, figured on the applied liquid. The proportion of acid formers and liquefiers was about the same as in the crude sewage.

At the close of the twenty-one months of experimentation the trickling filters were dug out and carefully examined. Samples of the filtering material were taken at various points; the accumulation between the stones was carefully removed by washing with a brush and the resulting liquor analyzed. In both filters the top of the beds was quite clean. In filter A there was an accumulation of fine material extending from 3 inches down for about a foot just under the four old distributors. This deposit covered four circles, each about a foot and a half in diameter, and was, of course, chargeable to the earlier imperfect process of distribution. In this layer, where the maximum deposit occurred, the extraneous matter amounted to .3 pound per cubic foot, of which 44 per cent. was organic. The remainder of filter A showed no visible accumulation of foreign material, and the underdrains and concrete floor of the bed were as clean as when they were laid. In filter B there was a slight deposit from 6 inches to 18 inches below the surface, amounting to .07 pound per cubic foot, while the remainder of the bed was clean. On the floor of B, however, there was a deposit of sludge half an inch thick, amounting to 4 cubic feet in all (1,720 cubic feet, or 64 cubic yards, per acre). This sludge contained 22 per cent. of water and 1.4 per cent. volatile solids. Qualitative tests showed it to consist of a mixture of finely divided silica with a considerable proportion of sulphide of iron.

From the stone analyses at various depths we have calculated in Table XVIII the total amounts of material stored in each filter and the corresponding values per million gallons. The excess of nitrogen on the septic side is suggestive.

TABLE XVIII — STORAGE OF MATERIAL IN TRICKLING FILTERS

	Pounds per Filter.			Pounds per Million Gallons.		
	Fixed solids.	Volatile solids.	Organic nitrogen.	Fixed solids.	Volatile solids.	Organic nitrogen.
Filter A. Crude sewage	36.4	5.5	0.6	14.6	2.2	0.2
Filter B. Septic sewage	5.3	6.6	2.7	2.1	2.6	1.1

In addition to these deposits in the beds the sludge on the bottom of filter B amounted to 697 pounds, or 280 pounds of dry solids, per million gallons. Such material could easily be removed by washing with a hose in a filter with a properly constructed underdrainage system.

VII. Sedimentation of Trickling Effluents

The effluents from the trickling filter, although stable, contain so much suspended matter as to be unsightly, and under many circumstances further treatment for the removal of suspended solids would be desirable. As shown at many of the English plants and at Columbus (Johnson, 1905), such a removal may be accomplished by simple sedimentation, since the suspended particles in the effluent are sufficiently large to settle out with ease. Since January, 1906, the effluents from filters A and B have been treated in this manner. The tanks used for sedimentation have been described above, and their general construction is indicated in Figures 1 and 2. One of the tanks, photographed before it was put into place, is shown in Figure 19.

The tanks were of conical form, with a central vertical funnel which received the inflowing liquid at the top and discharged it into the body of the tank near its bottom. The supernatant liquid was carried off from the top by two surface channels, and sludge was drawn off by a valve at the bottom. The capacity of each tank was a little under 350 gallons, equivalent to a sedimentation of an hour and three-quarters. Experiments made by Mr. R. R. Patch in a thesis study showed that liquid dyes colored the whole surface of the tank in seven and a half minutes. On the other hand, when a culture of *B. prodigiosus* was poured into the central tube, plates made every five minutes from the outflowing liquid first showed the germ after one hour and gave maximum numbers after an hour and a half.

The character of the effluent from the sedimentation tanks is indicated by the quarterly average analyses in Tables XIX and XX.

TABLE XIX — COMPOSITION OF FILTER A EFFLUENT AFTER SEDIMENTATION

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	115	45	116	56	4.2	3.9	13.0	0.6	3.9	31	26
1906	2	165	85	53	15	3.8	2.3	13.8	2.1	4.3	36	31
1906	3	100	45	55	20	5.8	4.2	6.3	2.5	4.0	29	25
1906	4	90	50	30	12	4.5	3.0	9.0	0.7	4.5	30	27
1907	1	160	85	50	11	3.0	2.0	9.5	0.5	5.5	29	26
1907	2	135	60	83	29	3.5	2.0	9.5	0.9	5.4	31	25
Average	..	128	62	65	24	4.1	2.9	10.2	1.2	4.6	31	27

TABLE XX — COMPOSITION OF FILTER B EFFLUENT AFTER SEDIMENTATION

Quarterly Averages

(Parts per Million)

Year.	Quarter.	Turbidity.	Sediment.	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Nitrites.	Nitrates.	Oxygen Consumed.	
				Total.	Fixed.	Total.	Solution.				Total.	Solution.
1906	1	90	30	40	14	3.9	3.2	15.0	0.1	4.4	26	23
1906	2	135	70	63	27	2.8	2.3	14.9	1.2	4.5	30	23
1906	3	76	45	31	11	5.2	4.0	10.7	2.9	4.6	30	28
1906	4	80	35	23	7	4.9	3.5	11.5	1.2	4.4	29	26
1907	1	115	50	34	12	2.5	1.5	10.5	0.8	5.0	31	28
1907	2	140	75	110	37	2.5	1.5	13.0	1.3	6.1	29	27
Average	..	106	51	50	18	3.6	2.7	12.6	1.3	4.8	29	26

A comparison of the general averages in Tables XIX and XX with the average for the unsettled effluents in Tables XIII and XIV indicates the efficiency of the sedimentation process, and this efficiency has been expressed in purification per cent. in Table XXI.

TABLE XXI — PERCENTAGE PURIFICATION EFFECTED BY SEDIMENTATION

	Suspended Solids.		Organic Nitrogen.		Free ammonia.	Oxygen Consumed.	
	Total.	Fixed.	Suspended.	Soluble.		Suspended.	Soluble.
A effluent	58	59	70	6	2	75	8*
B effluent	48	51	58	13*	0	66	4*

(* = increase.)

Sedimentation for two hours in the conical tanks used in these experiments removed about half the suspended solids present. The removal of suspended nitrogen and carbonaceous matter (oxygen consumed) was in each case greater than the removal of suspended matter in general. Coupled with the increase in soluble nitrogen and carbonaceous matter, this makes it clear that a certain amount of liquefying action went on at the bottom of the tanks. Nitrites and nitrates were unaffected, however, as may be seen by reference to Figure 17. It will be noticed that the per cent. purification effected was always less in the case of the septic effluent. This is, no doubt, because the liquid before treatment contained less gross material to remove. The finer portions of suspended matter naturally settle out less readily.

No important seasonal variations were noted in the action of the sedimentation tanks, except in the case of the organic nitrogen. This constituent, as plotted in Figure 7, was less reduced in the autumn months than at any other time, while at this period (the third quarter of 1906) the soluble organic nitrogen was largely increased. Its value rose from 3.6 to 4.2 in the case of A, and from 3.4 to 4 in the case of B effluent. This was, of course, due to the increased septic action going on in the tanks during the warm season. Bacterial results also indicated the existence of organic activity in the sedimentation tanks. The average number of bacteria in the settled effluent of filter B for the seven months — October, 1906, to April, 1907 — was 260,000 — an increase of 44 per cent. on the effluent entering the sedimentation tank.

The best measure of the efficiency of sedimentation is the methylene blue test, and the decolorization periods for the settled effluents are indicated by the unshaded blocks in Figures 18-*A* and 18-*B*. At times during the winter and spring of 1906 even the settled effluent was putrescible. In general, however, most of the effluents which putrefied in their

original state were rendered stable when their solids were reduced by sedimentation. The months of July and August, 1906, furnish a good instance of this. During the whole period forty-nine samples were examined. Of the unsettled effluents forty-five from filter A and twenty from filter B became decolorized inside of fourteen days, but of the corresponding sedimented samples only ten from filter A and nine from filter B became decolorized. After the new distribution system was in working order twenty-nine samples from A and twenty-seven samples from B decolorized in less than fourteen days. Of the corresponding settled samples thirteen from filter A and seventeen from filter B became decolorized.

It must be remembered in interpreting these results that our tanks were not of the best form for securing efficient sedimentation. Their shape was conditioned by the head room at our disposal, and a deeper tank, more of the usual Dortmund shape, would give better results. Furthermore, the pipe for removing sludge from our tanks was so small that sludge could not be drawn off rapidly, and considerable stirring up of the contents of the tank was the result. With tanks of proper design, planned for a full two-hour flow and with proper arrangements for sludge removal, results would undoubtedly be better.

Against the advantages to be gained by the sedimentation of the trickling effluent must be set the new problem of sludge disposal which is introduced. Since September, 1906, this problem has been studied by careful measurement and analysis of the material removed from the sedimentation tanks, and the general results are brought together in Table XXII. The analyses are grouped by four periods, in which the method of removing sludge from the tanks differed as follows: From September to December 3, 1906, and from April 9 to June 29, 1907, twenty-five gallons of sludge and water were drawn from each tank every other day by the valve for removing sludge shown in Figure 2. The three samples for each week were chloroformed, mixed, and analyzed. Reference to Table XXII shows that by this method the liquid removed from the tank was considerable in amount and contained only 10 to 20 per cent. of true sludge. If sludge is removed as often as this it cannot be obtained in very compact form in tanks of such a construction as ours. From December 4, 1906, to January 14, 1907, sludge was removed once a week, the tanks being drawn down to a point 2 feet from the bottom. In this way a more concentrated liquid was obtained. During the third

period (January 14 to April 8, 1907) no samples were taken. The sludge was allowed to accumulate, which produced no harmful results in the cold weather; and at the end of the period the tank was drawn

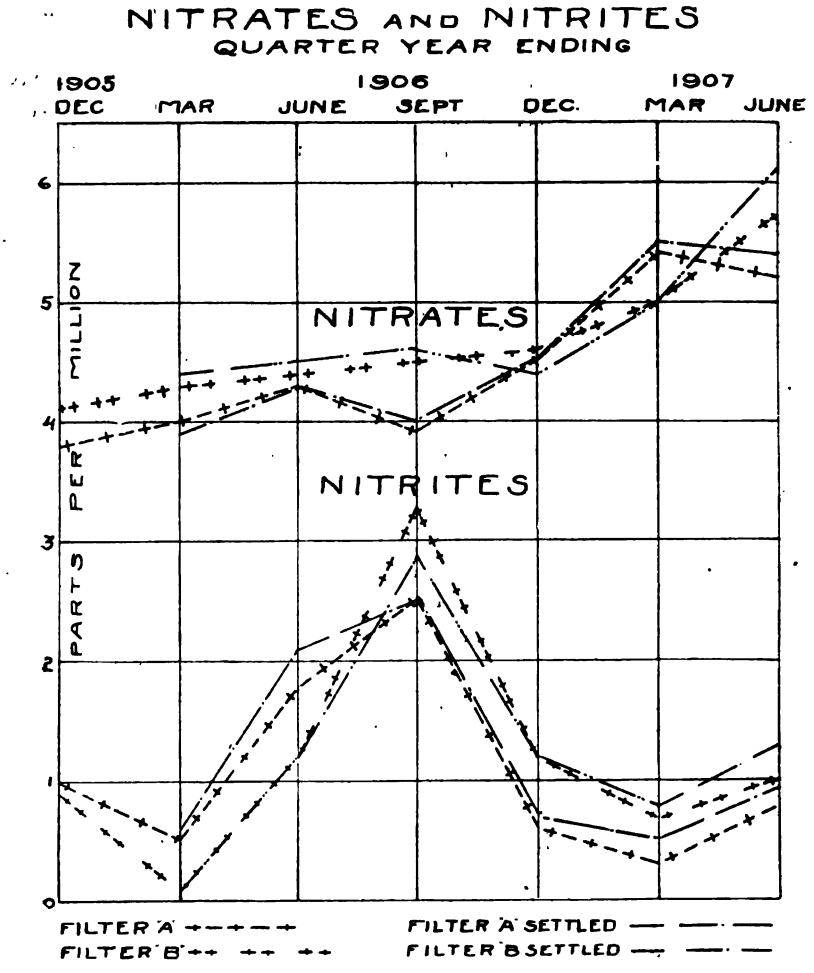

FIG. 17.—QUARTERLY VARIATIONS IN NITROGEN AS NITRATES AND NITRITES; CRUDE AND SETTLED EFFLUENTS

down to a depth of 1 foot 9 inches, and the remaining liquid removed and analyzed.

The cubic yards of wet sludge removed in each period varied for A effluent from .40 to 1.29 and for B effluent from .18 to .73. Per mil-

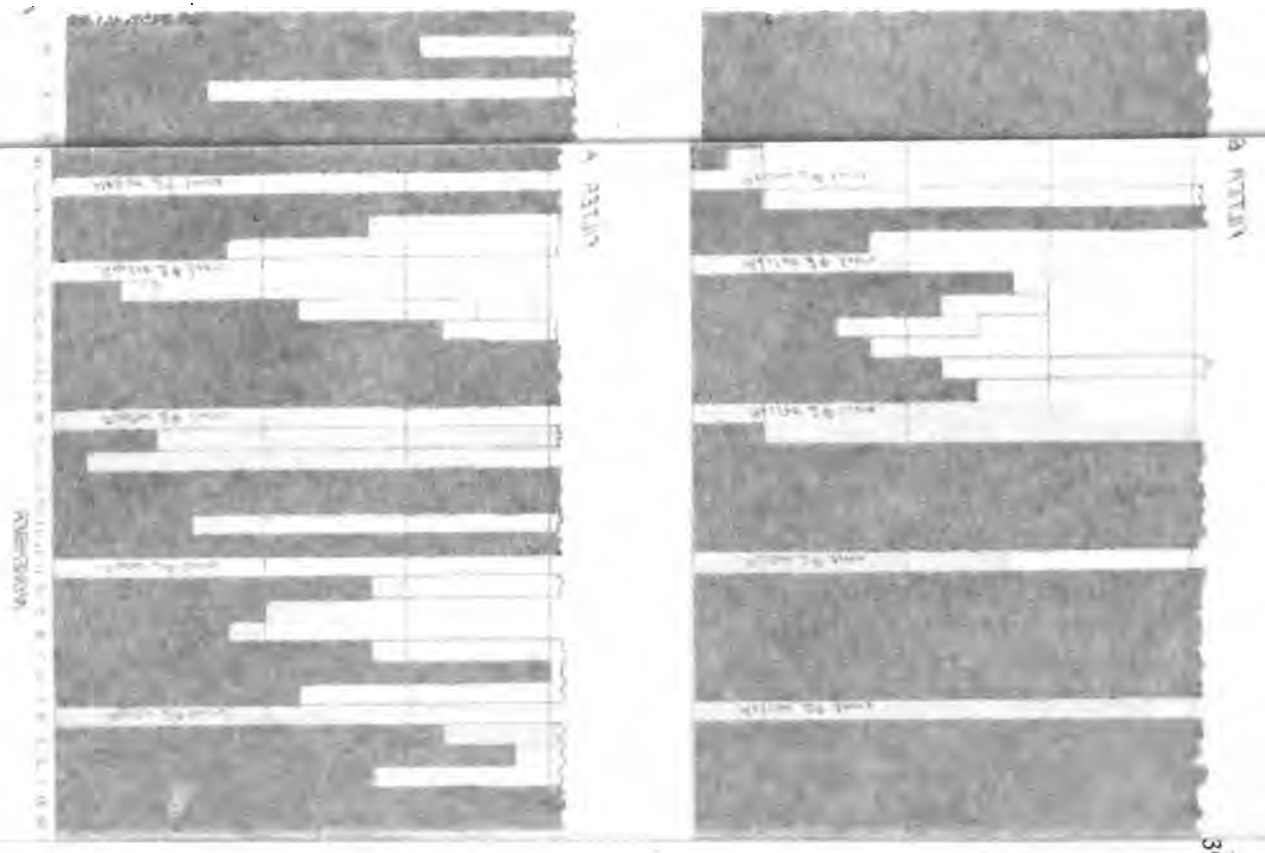

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TABLE XXII — AMOUNT AND COMPOSITION OF SLUDGE REMOVED FROM SEDIMENTATION TANKS

Period.	Total gallons sewage passed.	Gallons sludge and water removed.	Per cent. sludge.	Cubic yards wet sludge.	Analysis of Sludge, per Cent.					Pounds per Million Gallons Sewage.			
					Solids.		Organic nitrogen.	Carbon.	Specific gravity.	Solids.		Organic nitrogen.	Carbon.
					Loss.	Fixed.				Loss.	Fixed.		
A.													
September—December 3 . . .	276,000	825	15.5	0.636	4.07	5.07	0.195	0.45	1.049	155.0	193.0	7.40	17.10
December 4—January 14 . . .	151,800	90	90.5	0.405	4.32	5.84	0.190	0.45	1.049	184.5	257.0	8.35	19.80
January 15—April 8	285,200	490	38.0	0.925	3.72	3.81	0.150	0.35	1.034	200.0	206.0	8.06	18.90
April 9—June 29	246,000	900	29.0	1.290	4.22	5.12	0.215	0.30	1.028	361.0	439.0	18.40	25.80
B.													
September—December 3 . . .	276,000	825	10.2	0.420	3.81	3.85	0.223	0.45	1.045	96.5	97.5	5.70	11.40
December 4—January 14 . . .	151,800	90	42.0	0.185	3.99	4.43	0.195	0.38	1.042	82.6	92.1	4.05	7.89
January 15—April 8	285,200	490	30.0	0.730	3.30	3.56	0.220	0.20	1.036	138.0	151.0	9.40	8.50
April 9—June 29	246,000	900	16.0	0.712	4.53	3.39	0.205	0.33	1.025	220.0	165.0	9.96	16.10

lion gallons, the cubic yards of sludge removed were, for the four successive periods, 2.3, 2.7, 3.2, and 5.7 for filter A, and 1.5, 1.2, 2.6, and 2.9 for filter B. The increased values in the last two periods are due to the increased suspended solids in the effluents from the trickling beds during the spring rains. Taking the whole period from September to June, there were removed from the sedimentation tanks, per million gallons of sewage passed, on the crude sewage side, 3.40 cubic yards of sludge, with 237 pounds of volatile solids, 281 pounds of fixed solids, 11.2 of organic nitrogen, and 20.8 of organic carbon. On the septic side, per million gallons of sewage passed, there were 2.14 cubic yards of sludge, containing 136 pounds of volatile solids, 126 pounds of fixed solids, 7.5 pounds of organic nitrogen, and 11 pounds of organic carbon.

The volume of this sludge is evidently considerable. In composition it is naturally not so putrescible as its analysis would indicate, since it consists largely of the humus-like compounds formed in the trickling bed. Nevertheless, in concentrated form it is not generally stable, as shown by the fermentations already alluded to as going on in the sedimentation tanks. Mixed with the rest of the effluent these solids do not putrefy, as shown by the methylene blue tests of the unsettled effluent, and by the fact that nitrites and nitrates showed no diminution in the sedimentation tanks. By itself, however, the sludge will generally putrefy, and if it is removed by sedimentation some means must be found for its disposal. We attempted to purify it by straining through coke without success. Coarse coke allowed it to pass freely and fine coke clogged too rapidly to be of practical use. It will probably be found best under actual working conditions to discharge the tank contents on to sludge beds and dig the resulting deposit into the land. From the inconsiderable putrescibility of the sludge, this method of disposal could be accomplished with ease. It will, however, be a local question in each individual case whether the improvement effected in the trickling effluent by sedimentation compensates for the increased cost of settling and of sludge disposal.

VIII. Disinfection of Trickling Effluents

The trickling filter furnishes the best mechanism now available for accomplishing the primary object of sewage purification — the oxidation, or otherwise rendering stable, of organic matter. Often this is enough; but where shellfish industries or water supplies are menaced the bac-

teria too must be taken into account. For bacterial removal the rapid processes of sewage treatment are entirely inadequate. Comparing the effluent of filter B with the crude sewage, it is apparent that septic tank and trickling bed combined reduced the total number of bacteria from 1,200,000 to 180,000 — a diminution of 85 per cent. Tests for *B. coli* during the summer of 1906 gave the results indicated in Table XXIII, the figures representing the average of thirty-five determinations.

TABLE XXIII — BACTERIA IN SEWAGE AND SEPTIC AND TRICKLING EFFLUENTS

	Bacteria per c.c. Lactose agar at 37°.	*B. coli.* Positive tests* in $\frac{1}{1000000}$ c.c.
Sewage	1,300,000	65 per cent.
Trickling filter receiving sewage	750,000	35 per cent.
Septic effluent	1,650,000	66 per cent.
Trickling filter receiving septic effluent	750,000	35 per cent.

* By Jackson bile test.

Evidently during the warm weather there was a multiplication of bacteria in the septic tank, and the removal of total bacteria and of gas-forming organisms by the whole process was under 50 per cent.

These results are as good as can be expected from filters of coarse material, but they do not represent satisfactory bacterial purification. For this reason the Baltimore experts (Baltimore, 1906) suggested secondary filtration through sand for the effluents from their projected trickling filters, in order to avoid possible danger to the shellfish industry of Chesapeake Bay. The Board of Advisory Engineers estimated the cost of works for the complete treatment of 75,000,000 gallons of sewage per day at $3,283,250, of which sum $1,040,750, or over 31 per cent., was for the supplementary treatment on sand filters. The annual cost of operation was estimated at $115,500, of which $55,000, or 48 per cent., was for the supplementary treatment (Baltimore, 1906). This gives some idea of the price which it is necessary to pay for effluents of bacterial purity over and above the cost of rendering the sewage stable and non-putrefactive.

Fortunately a far cheaper and equally efficient method of removing bacteria is now at hand. The application of chemicals as a method of sewage purification — that is, as a method for the removal of organic material — has not proved successful except in rare instances,

with sewage of peculiar composition. When organic stability has been attained, however, and bacterial removal only is desired, the problem becomes a wholly different one. Disinfection of sewage and effluents has been studied by various English observers, most exhaustively by Rideal (1905). The latter observer, in an extensive series of experiments at Guildford, studied the action upon raw and septic sewage, and upon the effluents from contact beds, of hypochlorites produced electrolytically from sea water by the oxychloride process. Great reductions in bacteria were obtained with 30 to 70 parts per million of available chlorine for the crude sewage, 25 to 44 parts for septic sewage, and .5 to 20 parts for contact effluents of varying grades of purity. The removal of *B. coli* was all that could be desired. Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group, aërobic, spore-forming bacteria. Absolute sterilization, however, required very high concentration of chlorine. Since American sewages are weaker than European, and trickling effluents more highly purified than those of ordinary contact systems, the outlook for disinfection seemed more favorable under our conditions, for the less organic matter present the less chlorine will be absorbed and prevented from exerting its disinfectant action. Phelps and Carpenter (1906), in a study of the problem on a laboratory scale, obtained the results indicated in Table XXIV.

TABLE XXIV—DISINFECTION OF TRICKLING EFFLUENT BY BLEACHING POWDER

(Phelps and Carpenter, 1906)

Experiment No.	Available chlorine. Parts per million.	Organisms Killed. Per Cent. of Initial Numbers.				
		Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
I	3.5	98.7	. .	97.8	99.6	99.9
	10.6	98.9	. .	98.9	99.7	99.8
	55.0	99.9	. .	99.9	99.9	99.9
II	25.0	. .	99.8	99.9	. .	. .
	37.0	. .	99.94	. .	. .	. .
	100.0	. .	99.97	. .	. .	. .
III	2.0	. .	99.8	99.9	. .	. .
	5.0	. .	99.85	99.9	. .	. .
IV	0.25	. .	65.6	70.9	. .	. .
	0.50	. .	89.2	94.2	. .	. .
V	1.0	. .	81.5	99.1	. .	. .
	1.5	. .	99.6	99.9	. .	. .
VI	5.0	. .	98.2	98.2	. .	. .
	10.0	. .	. .	99.6	. .	. .

It was evident from these experiments that complete sterilization was a practical impossibility. Neither the addition of large amounts of bleaching powder, up to 100 parts of available chlorine per million, nor the storage of the effluent for periods of time up to twenty hours proved entirely effectual. On the other hand, a comparatively low concentration of chlorine applied for two hours gave a very large reduction, the residual organisms, as in Rideal's experiments, being

FIG. 19.—VIEW OF SEDIMENTATION TANK BEFORE IT WAS PUT IN PLACE

almost entirely saprophytic spore formers. Sterilization is not feasible, but disinfection is.

It is important to maintain the distinction between absolute sterilization and a reasonable percentage purification such as is obtained in water filtration. A neglect of this discrimination has led to the use of excessive quantities of lime in certain recent German experiments (Schumacher, 1905; Kranepuhl, 1907; Kurpjuweit, 1907). The character of the individual sewage, however, will of course materially affect

the results obtained in a given case. A good efficiency has been reported in recent experiments on the disinfection of septic effluent at Bengal, India. On the other hand, Kellerman, Pratt, and Kimberly (1907) found considerable amounts of chloride of lime necessary for the treatment of septic and contact effluents in Ohio.

In August, 1906, we began to treat the effluent from filter A by adding chloride of lime solution from a small orifice box to the effluent as it flowed into the sedimentation tank. The solution was mixed once a day in a fifty-gallon barrel in such strength that when added to the effluent at the rate of two gallons per hour it would supply the effluent with about five parts per million of available chlorine. It was not possible on such a small scale to regulate the flow accurately, and there was some variation in the amount of available chlorine added to the effluent. This value was determined each day when the samples were taken for bacterial examination. It averaged about five parts per million, and the variation was no more than may be expected in the case of a larger plant with less careful supervision. Samples were examined before the disinfectant was added and at the outflow from the tank after a little less than two hours' contact.

TABLE XXV — EFFICIENCY OF DISINFECTION OF TRICKLING EFFLUENT WITH CHLORIDE OF LIME

(Available Chlorine, Five Parts per Million)

Date.	Organisms per Cubic Centimeter.		Gas Production in Bile Broth.	
	Before treatment.	After treatment.	Before treatment. Dilution, $\frac{1}{1000000}$ c.c.	After treatment. Dilution, 1 c.c.
August, 1906				
11	270,000	69	+ 0	+ 0
13	630,000	41	0 0	+ 0
14	135,000	406	+ +	+ 0
15	230,000	21	0 0	0 0
16	250,000	37	+ 0	0 0
18	110,000	40	0 0	+ 0
20	90,000	54	+ 0	0 0
21	220,000	22	0 0	0 0
23	. .	. .	+ 0	0 0
Average	240,000	86	33 per cent.	22 per cent.
Average removal		99.96 per cent.		99.993 per cent.

The results of bacterial examinations on nine different days during the period, as indicated in Table XXV, show a 99.96 per cent. removal of total organisms. With Jackson's bile test positive results were obtained in 33 per cent. of the tests made upon the untreated effluent at a dilution of one millionth, indicating that the organism was present on the average to the extent of about 330,000 per cubic centimeter. After treatment, positive tests were obtained in 22 per cent. of 1 c.c. samples, indicating that on the average there was an organism present in 5 c.c. of effluent. Upon this basis the average removal of fermenting organisms (presumably *B. coli*) was 99.993 per cent.

These results were so favorable as to indicate the entire feasibility of disinfecting the effluent from trickling beds by means of chlorine. Five parts of chlorine, the amount necessary to secure practical disinfection, could be applied at a cost of $1.50 per million gallons of sewage. We desired, however, to compare the efficiency of other disinfecting agents. Johnson and Copeland (1905) obtained good results with copper sulphate, but used amounts of copper and periods of storage which would make the cost of the process prohibitive. When our filters were put in operation after their rest in September, 1906, experiments were begun with copper sulphate. One part of copperas sulphate per million was added to A effluent from October 13 to November 19, and from November 20 to December 2 two parts were used in the same way. During the first period the average of examinations on fourteen days showed 230,000 bacteria per cubic centimeter before treatment and 34,000 afterward — a reduction of 35 per cent. During the second period (with two parts of copper per million) the average of examinations on seven days showed 240,000 bacteria per cubic centimeter before treatment and 18,000 after — a reduction of 92.5 per cent. Evidently copper is inferior to chlorine for the treatment of this effluent, since the cost of one part of copper is about equal to that of five parts of chlorine.

During January and February, 1907, no disinfectant was added to the effluent from filter A. Simple sedimentation showed for the average of fifteen determinations a reduction from 140,000 bacteria to 42,000 — a diminution of 70 per cent. At higher temperatures, when multiplication takes place in the tank, no such reduction would, of course, be observed. As noted above, the tank receiving B effluent showed a considerable net increase of bacteria in the period from October to April.

March 1 experiments were begun with a third disinfectant, sodium benzoate, which has been suggested for use in this connection. In March and April, 0.8 part per million gallons was added, and in May the quantity was doubled. For the first period the average of tests on twenty-six different days showed 140,000 bacteria per cubic centimeter before treatment and 54,000 afterward — a reduction of 62 per cent. For the second period the average of five determinations showed 370,000 bacteria per cubic centimeter before treatment and 84,000 afterward — a reduction of 78 per cent. Evidently sodium benzoate is not an economical disinfectant, since the application of one part per million gallons would cost $1 per million gallons.

There is one important factor to be taken into account in interpreting these results, that of temperature. The action of disinfecting agents follows the velocity laws of other chemical reactions, and rises with an increase of temperature. The chlorine work was, therefore, carried out under somewhat more favorable conditions than the experiments with copper sulphate and sodium benzoate. The difference between chloride of lime and the other agents tested was so great, however, as to leave little question of the practical superiority of chlorine for the treatment of our effluent. Recent work carried out by one of us for the New Jersey State Sewerage Commission at Red Bank, New Jersey, has shown that chlorine disinfection is entirely feasible at a low cost and on a practical scale.

IX. Conclusions as to the Best Methods of Treating Boston Sewage, with an Estimate of Its Approximate Cost

1. *Trickling Beds.* — The main result of this investigation has been to show the feasibility of treating Boston sewage on trickling beds so as to secure organic stability. In the experiments conducted, the filters were operated at a rate of about two million gallons per acre per day, which would call for fifty acres of stone beds for the treatment of the sewage now discharged at Moon Island. A comparison with the 133 acres of contact beds or 1,000 acres of sand beds, which would be necessary for other processes, indicates clearly that for this city the trickling bed offers the most practical method of treatment.

We have found that with good distribution a trickling bed 8 feet deep will operate successfully at all seasons, under local weather con-

ditions. It removes about half the soluble organic matter, yielding an effluent which is somewhat turbid, but stable and well oxygenated. The organic matter present has been so worked over and purified by the bacteria in the filter as to be non-putrescible. Judged by the methylene blue reduction test 93 per cent. of the samples of the effluent are of such stability as to undergo no putrefactive change when kept closed up from the air for four days. Under ordinary conditions of discharge into open water such an effluent would be entirely unobjectionable.

The proper distribution on trickling beds can be attained either by the use of fixed sprinkler heads of the Columbus type, so arranged as to discharge intermittently at frequent intervals, or by the use of the splashing gravity distributors designed at the Experiment Station for this purpose.

With good distribution the trickling beds show no appreciable tendency to clog. During the greater part of the year solid matter accumulates on the surface of the stones throughout the bed, but when this storage reaches a certain point, usually in the early spring, the solids break away and come off in the effluent in a stable condition. In a period covering two years the total amount of solid matter coming off balanced that going on. The filtering material at the end of the experiments was in excellent condition and showed no storage of nitrogen.

Our results point strongly to the advantage of operating trickling beds under conditions as uniform as possible. Resting periods proved distinctly detrimental to the work of the beds, and constant operation is to be recommended rather than any process which involves alternate working and resting periods.

2. *Septic Tanks.* — It appears from our experiments that Boston sewage may be treated in the septic tank with excellent results, and that a period of seven hours is a sufficiently long one. Thus operated an open tank will remove 40 per cent. of the total suspended solids and 60 per cent. of the fixed suspended solids; its effluent shows a decrease of about 25 per cent. in organic nitrogen in solution and a corresponding increase in free ammonia. The septic action on the stored solids is an active one, four-fifths of the organic solids deposited disappearing in solution or as gas. Fixed solids gradually accumulate so as to render it probable that tanks would require cleaning about once in two years.

On the whole, our experiments indicate that the septic tank need

not be used at all in the treatment of Boston sewage. Since November, 1906, when the distribution system was put in order, crude sewage has been treated on one of our trickling beds with perfect success. The effluent from this filter was less frequently putrescible than that from the bed which received septic effluent. The filter taking septic effluent showed a deposit on its floor, due to secondary reducing changes, which was absent from the crude sewage bed. Furthermore, the absence of the odors produced by spraying septic sewage is an advantage of considerable moment in favor of the process of treating fresh sewage. Combined with the saving of the cost of tanks (in the neighborhood of $250,000), these arguments seem to indicate the treatment of crude sewage directly on trickling filters as most desirable. Modern devices for ensuring a thorough preliminary screening should, however, be installed.

3. *Sedimentation of Trickling Effluents.* — The suspended solids which appear in the trickling effluent, though inoffensive, are unsightly, and in many locations might require removal. By a sedimentation of two hours we have found it possible to remove about half the suspended solids. This clarification was accompanied by an improvement in stability.

In the case of Boston the currents of the harbor would be amply competent to care for the solid matter discharged if that matter were of an inoffensive and non-putrescible nature. Experience with the system at present in use has indicated this quite clearly. For a comparatively slight improvement in stability it does not appear to us justifiable to go to the expense of installing secondary sedimentation tanks. The sludge accumulating in such tanks would amount to two or three cubic yards per million gallons of effluent — a serious problem in itself. We are therefore of the opinion that the effluent from the trickling beds may best be discharged directly into the harbor as it comes from the beds. A stable effluent under such conditions could cause no nuisance, and if a submerged discharge were provided its presence would scarcely be detected.

4. *Disinfection of Trickling Effluent.* — The problem of bacterial purification still remains to be considered, since the trickling bed produces organic stability without destroying pathogenic bacteria. In the case of Boston Harbor, with its large contiguous population, its bathers, and its shellfish industry, this aspect is an important one. The experiments carried out during the last two years have made it clear that

the effluents from trickling beds may be so purified bacterially by disinfection with chloride of lime as to be of much better quality than the present streams entering Boston Harbor. This bacterial purification requires about five parts of available chlorine per million gallons, and the cost of treatment would be within moderate limits.

The process of disinfection with chlorine can be applied to crude sewage as well as to trickling effluent, although experiments carried out at the station indicate that about double the amount of chlorine is needed, on account of the reducing action of the organic matter in the sewage. Pending the construction of a trickling filter plant for the treatment of the organic matter in Boston sewage, it might well be purified bacterially by this process at the present Moon Island outfall.

5. *General Plan for the Treatment of the Sewage of the South Metropolitan District.* — The sewage outfall of the south Metropolitan district at Moon Island is the one which threatens most seriously to menace the purity of Boston Harbor, and it is this sewage which will certainly first require some different method of treatment. We have, therefore, considered in a general way the practical problem of dealing with it in the light of the results of our experiments.

The most convenient location for a trickling filter area would be at the calf pasture in Dorchester, near the present pumping station. This is objectionable, however, on account of its proximity to the thickly settled portion of Dorchester. Furthermore, the necessity for excavating about 10 feet of mud and refilling in its place would greatly increase the cost of construction at this point. The same objections apply to certain waste areas on the Neponset marshes which suggested themselves as possibly available. The headland of Squantum would offer an ideal opportunity for building trickling beds, but the difficulties of obtaining land in another town militate against the use of this site.

The southern portion of Thompson's Island would furnish a location free from all the objections to which the other sites are open. On an embankment 1,500 feet long the sewage could be carried from Squantum across to the island, the effluent flowing back along the same embankment to the existing outfall sewer. The pumping station at Dorchester and the tanks and outlet at Moon Island could thus be used without substantial changes. We have made preliminary estimates of the cost of building fifty acres of trickling beds, 8 feet deep, and equipped with the gravity distribution system, and are of the opinion that the cost,

including the embankment with its two sewers, an efficient grit chamber, a reasonable purchase price for the necessary land, grading, stone filling brought to the island by water, concrete construction, and sprinklers, would be in the neighborhood of $1,800,000.

If this capital sum were borrowed at 5 per cent. on a twenty-five year loan the annual expense for interest and sinking fund would be $126,800, paying off the entire cost in the twenty-five year period. As a matter of fact, we see no reason to suppose that at the end of this time the plant would not be good for another twenty-five years without substantial reconstruction. The cost of operation, including extra pumping and supervision of screens and filters, would amount to $70,000 a year, bringing the total cost to about $200,000 a year, or $5.50 per million gallons of sewage treated.[1]

The effluent from the trickling beds, wherever situated, could be further bacterially purified by disinfection with chloride of lime, at a cost of approximately $1.50 per million gallons, or $55,000 annually.

Pending the construction of filters for the removal of putrescible organic matter from Boston sewage, if it should seem desirable to secure bacterial purification, this may be effected by direct treatment of the crude sewage with chloride of lime, which could probably be done for $3 per million gallons, or $110,000 annually.

Experiments are now in progress at the Experiment Station to test the practicability of higher rates of filtration and shallower beds than those used in the experiments on which these calculations are based, as well as on the treatment of sewage and effluents by electrolytically produced chlorine. It is hoped that these experiments may lead to a material reduction in the estimated cost of the purification processes. It seems clear, however, that the combination of trickling filters and chemical disinfection will solve the Boston sewage problem satisfactorily; and in the light of present knowledge these two methods are the most efficient and economical available for the purpose.

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THE WILFLEY TABLE[1]

By ROBERT H. RICHARDS

THIS truly remarkable machine was built on a preliminary scale in May, 1895. The first full-sized table was built by Mr. A. R. Wilfley, and was used in his own mill in Kokomo in May, 1896. The first table sold for installation was placed in the Puzzle Mill, Breckinridge County, in August, 1896.

The mill enthusiasts at first hailed it as the cure for all the ills that flesh is heir to in the milling line. A little later it was found to make losses which were serious, and on this account the table succeeded only to a limited extent in displacing the vanners of the gold mills. Still later, mill men in a number of districts throughout the country made special studies of the faults of the machine, and devised a number of ways of grouping supplementary machines to overcome as far as possible the losses, and at the same time retain the benefit of the extraordinarily large capacity accompanied by the production of clean concentrates for which the machine has become so justly famous. I hope to make an exhibit of some of these methods in an appendix to my book on ore dressing which is now in preparation. These experimenters have not written up the subject, and if they possess all the facts they have not given them out for the benefit of the mining profession at large.

The object of this paper is to obtain the facts and to present them so clearly that their bearing can be seen by all. To this end two complete series of tests have been planned. One (the present paper), to study concentration of galena in presence of quartz; the other (to follow shortly), to study concentration of chalcopyrite in presence of quartz.

Some authorities claim that the table does its best work when treating natural products; by this phrase I mean products which have been

[1] Transactions of the American Institute of Mining Engineers, Toronto meeting, July, 1907.

crushed to pass through a limiting sieve, but have had no other preparation whatever; in consequence they have all sizes of grains of both the heavy valuable mineral and the light waste gangue, ranging from the largest grains that can pass through the sieve down to the finest dust.

Others claim that the ore fed to a Wilfley table should be closely sized before it is fed. That is to say, it should be divided by a series of sieves ranging from coarse to fine into a series of products with sizes of grain ranging from coarse grains to fine grains; and that each of these products, in which the grains of the heavy mineral are of approximately the same diameter as the grains of the light mineral, should be fed to the Wilfley table.

Still a third group of authorities claims that the ore before being fed to a Wilfley table should be classified by a hydraulic classifier, which divides the crushed ore into a series of products ranging, like the sized products, from coarse grains to fine grains, by carrying it in a water current over a series of apertures or vertical pipes, called sorting columns, up through which water currents are passing. These currents are graded from faster to slower, and therefore allow only the heaviest grains to settle down through the first sorting column and out through the spigot; while lighter, smaller grains settle in the second, and still lighter in the third, and so on, diminishing until the last sorting column and spigot give very small grains, and the overflow has the finest grains of all. The classified products differ greatly from the sized products in that the grains of heavy mineral are much smaller in diameter than the light grains with which they settle, and therefore behave in a somewhat different way upon the Wilfley table from the sized products. It should be said that the first spigot product of a classifier differs from the others in having coarse grains of heavy mineral present also.

The usual division of products upon a Wilfley table is easily and naturally made, as shown in Figure 1, *A* being concentrates; *B*, middlings; *C*, tailings, and *D*, slimes. Of these, when natural products are fed, the concentrates, *A*, are nearly clean, heavy mineral, a slight contamination of small grains of quartz being present. The middlings, *B*, carry some large grains and also some small grains of heavy mineral. The tailings, *C*, carry some very small grains of heavy mineral, and the slimes, *D*, carry very minute grains of heavy mineral.

I believe that the small grains of heavy mineral in middlings, *B*,

and tailings, *C*, are of less diameter than the smallest in the concentrates, *A*, and of greater diameter than the majority in the slimes, *D*, and that they belong in middlings and tailings from the law of their existence. The re-running of such middlings upon the same table is therefore not a wise proceeding, and only admissible as an expedient in small establishments when the quantity of middlings is not sufficient to warrant other provision. So much for the speculation before the investigation was made.

The materials for this test were pure white massive quartz for the light mineral, and crystalline galena, nearly free from blende and other impurities, from Joplin, Missouri, for the heavy mineral. The quan-

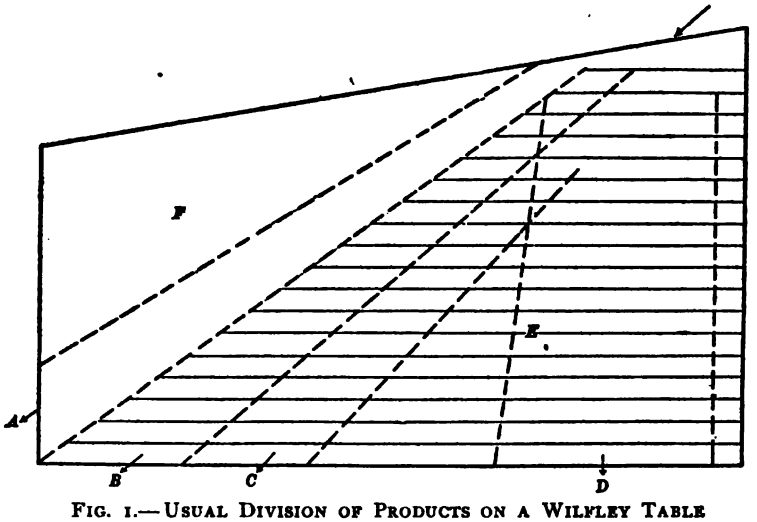

FIG. 1.—USUAL DIVISION OF PRODUCTS ON A WILFLEY TABLE

tities of these impurities were so small as to have little effect on the results. Both minerals were broken down to 2-mm. size, and mixed so as to have approximately 10 per cent. of galena and 90 per cent. of quartz.

The Wilfley table used for the tests had a net working surface of 2 feet by 4 feet. This is the table that has been found very satisfactory for students' work at the Massachusetts Institute of Technology. An error is present to a slight extent in the full-sized table, 16 feet long by 7 feet wide, and to a serious extent in the small Wilfley testing table, 7 feet long, found in some of the schools. It is due to tacking tapered riffle cleats on to a linoleum plane surface, thereby making two

planes: first, the roughing plane over the riffle cleats, *E*, Figure 1; second, the cleaning plane or part where there are no riffles, *F*, Figure 1. These two planes make an angle with each other, or a slight trough, which heaps up the sands deeper than is wise along the line of the tips of the riffle cleats. This error is completely overcome on the little table here used by cutting the riffles down into the wooden surface of the table. The roughing and cleaning planes are therefore one and the same plane. By observing this precaution I believe that this little table is able to do as good work as the full-sized table.

Comparing the little table with the full-sized table as to areas and capacity, assuming that their capacities are proportional to their areas, we have Table I.

TABLE I—AREA AND CAPACITY OF SMALL AND LARGE WILFLEY TABLES

	Little table.	Large table.
Area	8.0 square feet	112.0 square feet
Feed	1.0 kilogram per minute	22.0 tons per 24 hours
Feed	0.75 kilogram per minute	16.6 tons per 24 hours
Feed	0.5 kilogram per minute	11.0 tons per 24 hours

These figures represent the usual range used in practice.

Seventeen runs in all were made; Nos. 1 to 5, inclusive, were made upon natural products, the several feed-products being 2 mm. to 0; 1 mm. to 0; 0.5 mm. to 0; 0.25 mm. to 0; and 2 mm. to 0. Run No. 5, although fed with the same size as No. 1, was fed at a different rate. In making these runs no effort was made to re-run the middlings; first, because the concentrates and tailings would both have been contaminated and would not have shown as well; second, because the middlings themselves would have undergone a change in composition. In consequence of this ruling, the quantities of middlings appear abnormally large.

In these runs the dividing line between concentrates and middlings was chosen so as to make concentrates nearly clean to the eye. The dividing line between middlings and tailings was chosen so as to keep all the large grains of heavy mineral in the middlings. The four products—concentrates, middlings, tailings, and slimes—were sized on a series of sieves, and the quartz in them determined by dissolving out the galena in hydrochloric acid. The galena was determined by difference.

Runs Nos. 6 to 11, inclusive, were all upon sized products, and the results obtained are given in Table II.

TABLE II—SIZES AND WEIGHTS OF MATERIALS FED TO TABLE. TESTS NOS. 6 TO 11

Run No.	Sieves Diameter.		Actual Weights.
	Through.	On.	Fed.
	mm.	mm.	kg.
6	2.0	1.4	12.15
7	1.4	1.0	6.74
8	1.0	0.75	4.93
9	0.75	0.5	2.85
10	0.5	0.36	1.70
11	0.36	0.28	1.55
. .	0.28	0.0	3.06
			33.00

The total quantity weighed 33 kg., of which 30 kg. was quartz and 3 kg. was galena. The guiding was done simply to make clean concentrates and tailings. The middlings were in every case re-run until they could not be further reduced without contaminating the concentrates or the tailings. Where a sized ore is free from included grains and from any middle weight mineral, the feeding back of the middlings on the same table is logically good practice, because the middlings product is simply a mixture of concentrates and tailings; therefore, they could be fed back on the same table and disappear entirely without harm to concentrates or tailings.

Runs Nos. 12 to 17, inclusive, were made upon sorted or classified products. The classifier (Figure 2) had twelve closed spigots or blind spigots; that is to say, spigots which discharged sand into 2-gallon bottles as fast as it came, but discharged no water. The sorting columns were of 0.5-inch pipe, squared at the top and 3 inches long. Expressed in millimeters per second, the rising currents in the successive sorting columns were: 105, 85, 69, 55, 45, 36, 29, 23, 19, 15, 12, 10, respectively. The thirteenth spigot had no rising current, and it was simply a safety spigot to prevent any accumulation of sand that was too light to go down in the twelfth and too heavy to go over into the overflow. This apparatus gives a set of products beautifully classified.

To define the classified products more completely, a small aliquot

TABLE III — DISTRIBUTION OF QUARTZ AND GALENA IN RUNS NOS. 12 TO 17

Run No.		12			13			14					
No. of spigot		1			2			3			4		
Actual weight in kg.		15.110			15.775			11.175			5.170		
Rising current, mm. per second		105			85			69			55		
Through.	On.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.	Quartz.	Galena.	Middlings.
mm.	mm.												
2.83	2.49	0.052	0.004	0.007	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.49	2.06	2.408	0.709	0.021	1.517	. .	. .	0.213	. .	. .	. .	. .	. .
2.06	1.63	17.170	7.216	0.085	20.299	. .	0.006	3.617	. .	0.003	0.112	. .	. .
1.63	1.44	9.885	7.650	0.112	20 805	0.004	0.009	6.510	0.002	0 003	0.394	. .	. .
1.44	1.27	9.381	8.476	0.118	19.856	0.003	0 013	12.635	0 003	0 004	1.210	. .	. .
1.27	1.10	2.480	3.391	0.010	15.746	0.004	0.016	14.249	0 002	0 002	3.475	. .	0.001
1.10	0.97	1.945	3.742	0.022	5.161	0.006	0.011	14.339	0.003	0.0 1	2.573	. .	0.001
0.97	0.84	2.041	5.435	0.025	5.925	0.037	0.023	15.208	0 027	. .	9.530	0.006	. .
0.84	0.68	0 861	3.914	0 020	2.734	0 063	0.017	10.646	0 018	. .	12.793	0.008	. .
0.68	0.57	0 535	3.479	0 009	1.527	0.147	0.013	7.499	0 030	. .	20.128	0.037	. .
0.57	0.45	0.356	4.143	. .	1.558	0.865	. .	8.795	0.167	. .	26 312	0.056	. .
0.45	0.36	0 100	1.634	. .	0.217	0.678	. .	1.437	0.203	. .	9.741	0.070	. .
0.36	0.28	0.068	1.407	. .	0.107	1.215	. .	0.942	0.678	. .	6.502	0.275	. .
0.28	0.24	0.022	0.457	. .	0 028	0.517	. .	0.190	0.455	. .	1.638	0.489	. .
0.24	0.20	0.016	0.258	. .	0 015	0.414	. .	0.124	0 825	. .	0.667	0.892	. .
0.20	0.15	0.010	0.145	. .	0.009	0.233	. .	0.045	0.594	. .	0.223	1 107	. .
0.15	0.12	0.007	0.089	. .	0.005	0.107	. .	0 013	0.295	. .	0 068	0.715	. .
0.12	0.10	0.001	0.018	. .	0.003	0 025	. .	0.007	0 093	. .	0.037	0.458	. .
0.10	0.08	0.007	0 037	. .	0.005	0 029	. .	0 010	0.102	. .	0.025	0.301	. .
0.08	0.00	0.007	0.037	. .	0.009	0.023	. .	0.090	0.050	. .	0.012	0.132	. .
Total		47.352	52.261	0 429	95.526	4.370	0.108	96.569	3.587	0.013	95.440	4.546	0.002
Settling ratio		1.58			4.11			3.93			3.26		

TABLE III — *Continued*

Run No.		15				16						17							
No. of spigot		5		6		7		8		9		10		11		12		Overflow.	
Actual weight in kg.		2.280		1.950		1.182		0.389		0.962		0.765		0.651		0.705		1.860	
Rising current, mm. per second		45		36		29		23		19		15		12		10			
Through.	On.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.
mm.	mm.																		
2.83	2.49	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.49	2.06	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.06	1.63	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.63	1.44	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.44	1.27	0.031	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.27	1.10	0.132	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.10	0.97	0.184	. .	0.015	. .	0.008	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.97	0.84	1.467	. .	0.082	. .	0.017	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.84	0.68	5.161	. .	0.949	. .	0.042	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.68	0.57	5.200	0.009	1.668	. .	0.220	. .	. .	. .	0.010	. .	. .	. .	. .	. .	. .	. .	. .	. .
0.57	0.45	29.990	0.057	16.732	. .	3.133	. .	0.150	0.101	0.073	. .	0.026	. .	. .	. .	. .	. .	. .	. .
0.45	0.36	25.038	0.026	18.590	0.380	9.086	0.084	5.156	0.125	1.850	0.135	0.040	. .	. .	. .	. .	. .	. .	. .
0.36	0.28	19.164	0.119	34.011	0.272	36.110	0.338	20.250	0.125	13.185	0.260	6.799	0.171	1.251	0.015	0.114	0.014	0.169	0.238
0.28	0.24	4.779	0.132	9.752	0.082	15.539	0.160	23.252	0.225	14.806	0.291	3.980	0.026	3.961	0.104	0.528	0.057	0.185	0.195
0.24	0.20	2.280	0.435	8.884	0.257	17.499	0.253	26.435	0.350	29.790	0.364	23.061	0.132	12.375	0.134	5.083	0.129	0.723	0.486
0.20	0.15	0.725	1.019	2.171	0.406	7.127	0.296	12.740	0.275	17.320	0.281	29.820	0.211	25.773	0.223	11.593	1.157	2.243	0.438
0.15	0.12	0.242	1.612	1.011	1.273	3.344	0.828	3.755	0.325	11.813	0.416	18.685	0.303	26.653	0.298	21.415	1.999	10.116	0.950
0.12	0.10	0.119	0.663	0.205	1.232	0.650	0.769	0.901	0.526	2.275	0.499	5.455	0.329	11.615	0.268	11.464	1.171	8.575	0.522
0.10	0.08	0.018	0.474	0.092	1.140	0.507	2.111	0.951	2.203	1.299	2.005	3.321	1.186	7.787	0.819	20.500	2.413	28.520	1.805
0.08	0.00	0.048	0.879	0.046	0.739	0.228	1.647	0.225	1.902	0.416	2.910	1.700	4.744	3.529	5.182	17.475	4.982	35.460	9.372
Total		94.578	5.425	94.208	5.781	93.510	6.486	93.815	6.157	92.837	6.261	92.887	7.102	92.944	7.043	88.172	11.922	85.991	14.006
Settling ratio		3.19		2.62		2.49		2.21		2.21		2.74		2.46		1.28		1.10	

part of each was sized, photographed, and analyzed. The photograph, Figure 3, shows to the eye the distribution of sizes in each spigot. Table III shows the distribution of quartz and galena in the different sizes of each spigot. Expressed in millimeters, the sieve sizes used were: 2.83, 2.49, 2.06, 1.63, 1.44, 1.27, 1.10, 0.97, 0.84, 0.68, 0.57, 0.45, 0.36, 0.28, 0.24, 0.20, 0.15, 0.12, 0.10, 0.08. The middlings picked out and weighed for the first four spigots consisted of blende and galena included grains, with some free blende grains. Their use here is sim-

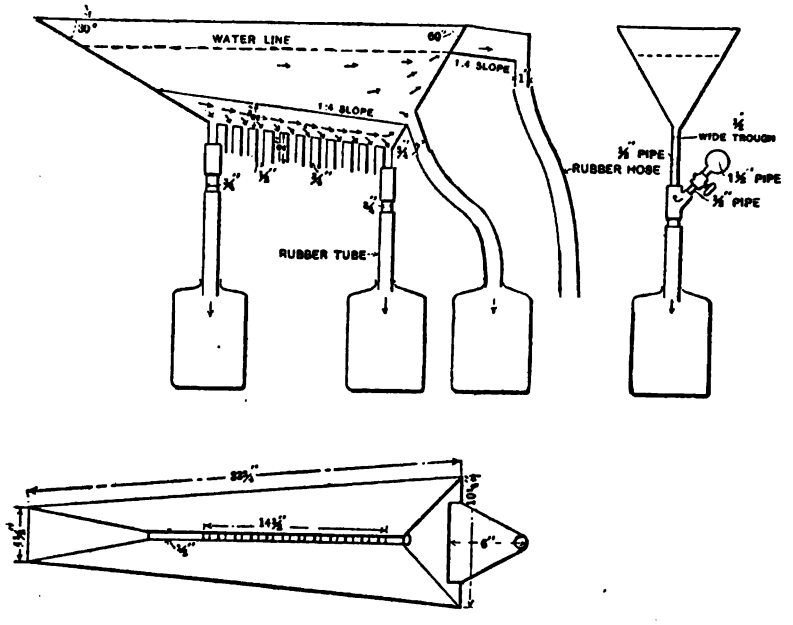

FIG. 2.—CLASSIFIER USED FOR RUNS NOS. 12 TO 17

ply to show how nearly pure the galena was. The settling ratios are of special interest; for example, at the foot of spigot No. 4 we have the settling ratio, 3.26, which signifies that in spigot No. 4 the average diameter of the quartz grains is 3.26 times the average diameter of the galena grains. The method of computing these ratios is given in my paper, "Close Sizing before Jigging."[1] It was thought wiser to combine the spigots somewhat instead of making twelve separate runs; accordingly, the six runs were fed with products as follows: First spigot; second spigot; third and fourth together; fifth and sixth

[1] Trans., XXIV, 449, 450 (1894).

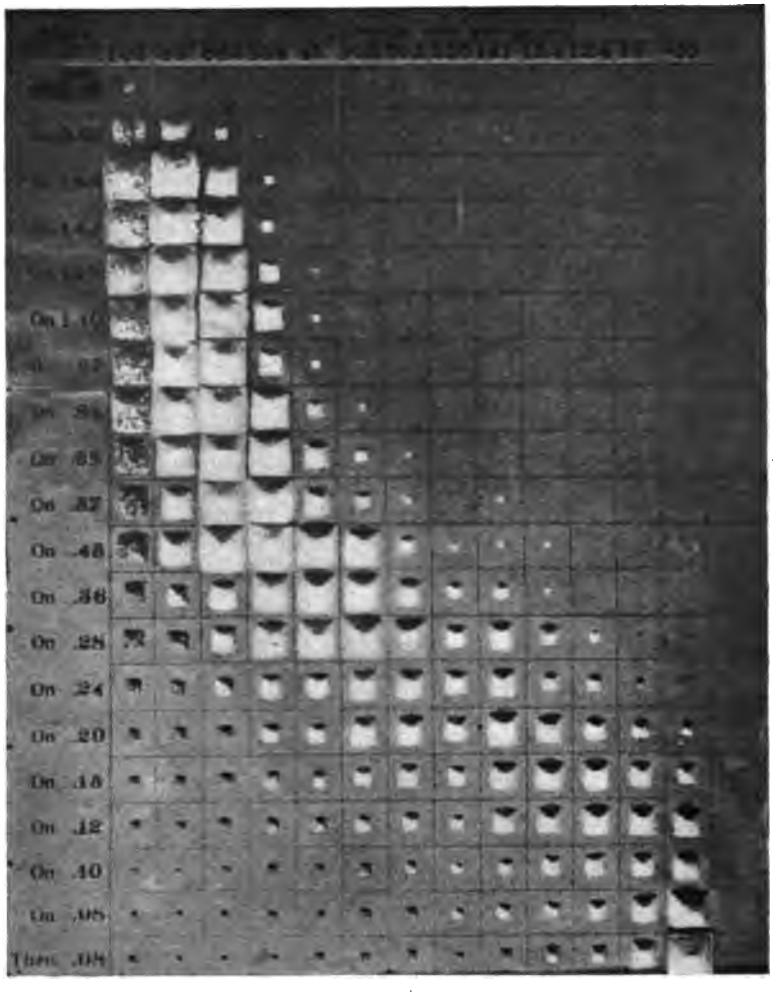

FIG. 3.—DISTRIBUTION OF SIZES BY THE CLASSIFIER

together; seventh, eighth, and ninth together; tenth, eleventh, and twelfth together.

The first five runs on natural products computed on the basis of a 100-ton lot, and to the rate of feeding of a full-sized table, gave products shown in Table IV.

TABLE IV — RESULTS OF RUNS NOS. 1 TO 5

	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Size of feed	mm. 2 to 0	mm. 1 to 0	mm. 0.5 to 0	mm. 0.25 to 0	mm. 2 to 0
Rate of feed per twenty-four hours	Tons. 22	Tons. 22	Tons. 11	Tons. 11	Tons. 11
Concentrates	4.114	2.973	4.667	5.343	2.808
Middlings	21.486	20.750	25.981	21.028	45.538
Tailings	72.856	72.903	62.813	60.487	50.688
Slimes	1.544	3.374	6.539	13.142	0.966
Total	100.000	100.000	100.000	100.000	100.000

The next six runs on sized products, computed on the basis of a 100-ton lot, and to the rate of feeding of a full-sized table, gave products shown in Table V.

TABLE V — RESULTS OF RUNS NOS. 6 TO 11

	Run No. 6.	Run No. 7.	Run No. 8.	Run No. 9.	Run No. 10.	Run No. 11.
Size of feed	mm. 2 to 1.4	mm. 1.4 to 1	mm. 1 to 0.75	mm. 0.75 to 0.50	mm. 0.50 to 0.36	mm. 0.36 to 0.28
Rate of feed per twenty-four hours	Tons. 22	Tons. 16.6	Tons. 11	Tons. 11	Tons. 11	Tons. 11
Concentrates	6.537	9.728	12.064	13.168	12.171	15.137
Middlings	1.647	1.901	1.694	1.602	5.310	3.170
Tailings	91.816	88.371	86.242	85.230	82.519	81.693
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

The last six runs, computed on the basis of 100-ton lots, and to the rate of feeding of a full-sized table, gave products shown in Table VI.

TABLE VI — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL-SIZED TABLE

	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
Classifier spigots, numbers that were fed	1	2	3, 4	5, 6	7, 8, 9	10, 11, 12
Classifier currents, mm. per second through which grains settled	105	85	55.4	36.3	19.1	10
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Rate of feed to Wilfley, twenty-four hours	11	11	16.6	11	11	11
Concentrates	49.649	3.950	3.398	4.940	5.7165	4.980
Middlings	5.534	1.307	0.663	0.828	1.0435	4.262
Tailings	44.817	94.743	95.939	94.232	93.240	90.758
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

Comparing the seventeen runs as to quantity of the products without looking at the quality, it will be noticed at once that the concentrates and tailings in runs Nos. 6 to 11 and Nos. 12 to 17 are very much larger in quantity than these products in runs Nos. 1 to 5; while the middlings are very much smaller in quantity.

A comprehensive table of all seventeen runs is given in Table VII, which shows the proportions of concentrates, middlings, tailings, and slimes in each, and also the percentage of galena and quartz in the various products.

Tables VIII, IX, X, and XI give the weights in tons of the different sizes, and also the proportion of quartz and galena in each product by sizes.

In comparing the analyses of the concentrates of these five runs (Table VIII), we see a very remarkable similarity in the behavior of the quartz and galena through all five runs. The coarser sizes and the finer sizes are almost clean galena, being nearly free from quartz. At a point somewhere a little below the middle, the quartz rises to a maximum, which in the first run reaches 18.99 per cent. of quartz, in the third run reaches 7.38 per cent. of quartz, and in the fifth run reaches 13.80 per cent. of quartz.

Comparing the different analyses of the middlings (Table IX), we find the galena among the very largest and smallest grains gives a very high percentage, and down to a little below the middle the galena runs down to a very low percentage, while the quartz behaves just in the opposite way. This is analogous to the composition of the concentrates.

TABLE VII — SUMMARY OF RESULTS OF RUNS NOS. 1 to 17

No. of run.	Size.	Rate of Feeding.		Composition of the Feed.		Percentage of the Products.				Composition of Products.								Per Cent. of Total Galena.				Total quantity actually fed.
		Kilogram per minute.	Tons 24 hours, large table.			Concentrates.	Middlings.	Tailings.	Slimes.	Concentrates.		Middlings.		Tailings.		Slimes.		Concentrates.	Middlings.	Tailings.	Slimes.	
				Quartz.	Galena.					Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.					
	mm.			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Kg.
1	2 to 0	1.0	22.0	90.91	9.09	4.11	21.48	72.87	1.54	9.92	90.08	76.42	23.58	99.49	0.51	81.10	18.90	39.20	53.34	3.82	3.64	11.00
2	1 to 0	1.0	22.0	90.91	9.09	2.97	20.75	72.91	3.37	8.50	91.50	73.37	26.63	99.39	0.61	90,29	9.71	34.58	57.34	4.72	3.36	11.00
3	0.5 to 0	0.5	11.0	90.91	9.09	4.67	25.98	62.81	6.54	2.40	97.60	84.10	15.90	99.10	0.90	87.82	12.18	44.86	41.98	5.44	7.72	11.00
4	0.25 to 0	0.5	11.0	90.91	9.09	5.34	21.03	60.49	13.14	2.27	97.73	87.16	12.84	98.39	1.61	90.04	9.96	51.48	27.59	8.20	12.73	11.00
5	2 to 0	0.5	11.0	90.91	9.09	2.80	45.67	50.30	1.23	4.66	95.34	86.29	13.71	99.71	0.29	85.38	14.62	29.06	67.79	1.62	1.53	9.63
6	2 to 1.4	1.0	22.0	92.60	7.40	6.54	1.65	91.81	. .	0.77	99.23	40.33	59.67	99.96	0.04	. .	. .	87.43	12.05	0.52	. .	12.08
7	1.4 to 1	0.75	16.6	89.08	10.92	9.73	1.90	88.37	. .	0.77	99.23	76.90	23.10	100.00	0.00	. .	. .	96.43	3.57	0.00	. .	6.74
8	1 to 0.75	0.5	11.0	87.32	12.68	12.06	1.69	86.25	. .	0.99	99.01	83.00	17.00	99.91	0.09	. .	. .	97.62	1.80	0.58	. .	4.93
9	0.75 to 0.5	0.5	11.0	87.15	12.85	13.15	1.60	85.25	. .	2.50	97.50	77.40	22.60	99.65	0.35	. .	. .	96.58	2.29	1.13	. .	2.845
10	0.5 to 0.36	0.5	11.0	85.92	14.08	12.18	5.31	82.51	. .	0.69	99.31	80.03	19.97	99.76	0.24	. .	. .	90.57	7.95	1.48	. .	1.72
11	0.36 to 0.28	0.5	11.0	85.70	14.30	15.10	3.17	81.73	. .	2.14	97.86	84.67	15.35	99.56	0.44	. .	. .	94.60	3.10	2.30	. .	1.59
	Classifier																					
12	1st spigot	0.5	11.0	49.82	50.18	49.65	5.53	44.82	. .	0.74	99.26	86.15	13.85	99.71	0.29	. .	. .	98.21	1.53	0.26	. .	13.60
13	2d spigot	0.5	11.0	95.21	4.79	3.95	1.31	94.74	. .	1.38	98.62	66.05	33.95	99.64	0.36	. .	. .	81.35	10.72	7.93	. .	14.197
14	3 and 4 spigot	0.75	16.6	96.23	3.77	3.40	0.66	95.94	. .	1.15	98.85	65.57	34.43	99.80	0.20	. .	. .	88.95	5.98	5.07	. .	14.629
15	5 and 6 spigot	0.5	11.0	94.39	5.61	4.94	0.83	94.23	. .	1.65	98.35	71.10	28.90	99.45	0.55	. .	. .	86.66	4.29	9.05	. .	3.745
16	7, 8, 9 spigot	0.5	11.0	93.74	6.26	5.72	1.04	93.24	. .	1.16	98.84	83.75	16.25	99.54	0.46	. .	. .	90.58	2.90	6.52	. .	2.28
17	10, 11, 12 spigot	0.5	11.0	93.73	6.27	4.98	4.26	90.76	. .	0.38	99.62	83.72	16.28	99.34	0.66	. .	. .	79.38	10.69	9.93	. .	1.9

Comparing the tailings of the five runs (Table X), we note that the galena appears only to a very slight degree in any of the tailings until we get down to the smaller sizes, and there we have figures that rise to an almost alarming size, the first run giving 17.5 per cent. of galena in the finest size; the second, 17.8 per cent.; the fifth run giving 12.17 per cent. in the finest size.

The slimes (Table XI), which have a serious quantity of material only in the finest size, have also a serious percentage of lead in that finest size. The other percentages of lead are generally much smaller. There are three exceptions, in the second, third, and fourth runs, where the percentages run high in the larger sizes, but the quantity is so small that these losses are insignificant.

Commenting upon runs Nos. 6 to 11 (Table XII), as compared with runs Nos. 1 to 5, we note immediately that the concentrates all the way through are almost pure galena with scarcely any quartz, and the tailings are almost pure quartz and scarcely any galena. The middlings, as remarked before, are so small in quantity that they affect the runs but little, and when we consider that they can go directly back on to the table in the continuous run, they do not affect the result at all. This set of runs, Nos. 6 to 11, therefore appears to distance runs Nos. 1 to 5 in the competition. There is really no comparison, since runs Nos. 1 to 5 are not in the same class with them.

Comparing the concentrates of runs Nos. 12 to 17 (Table XIII), we see in the first place an enormous heaping up of concentrates in run No. 12. The weight, forty-nine tons, is more than double the weight of all the other five runs in this set put together. This heaping up of the great quantity of concentrates on the table which treats the first spigot of a classifier is one of the prominent features of the use of a classifier in preparation for feeding Wilfley tables. If we look at the total percentages of galena and quartz in the concentrates of run No. 12, we see that they contain 99.26 per cent. of galena and 0.74 per cent. of quartz. This makes an extremely good showing, and one which bids for favorable consideration of the classifier set.

Looking at the later spigots, that is to say, runs Nos. 13 to 17, inclusive, in the analyses, we see that the percentage of quartz looks high in the coarser sizes. This would seem a serious disadvantage if it were not for the fact that these products which have the high percentages of quartz are so small in quantity that the quartz cuts scarcely any figure in the final percentage of quartz in the concentrates. Alto-

gether this set of concentrates is so good that it would be accepted by any mill, even the Missouri mills, where such clean concentration is required.

Looking at the middlings (Table XIV), we see that the quantity is extremely small, and can be made to disappear in a continuous run by feeding them back on to the table without harming either the concen-

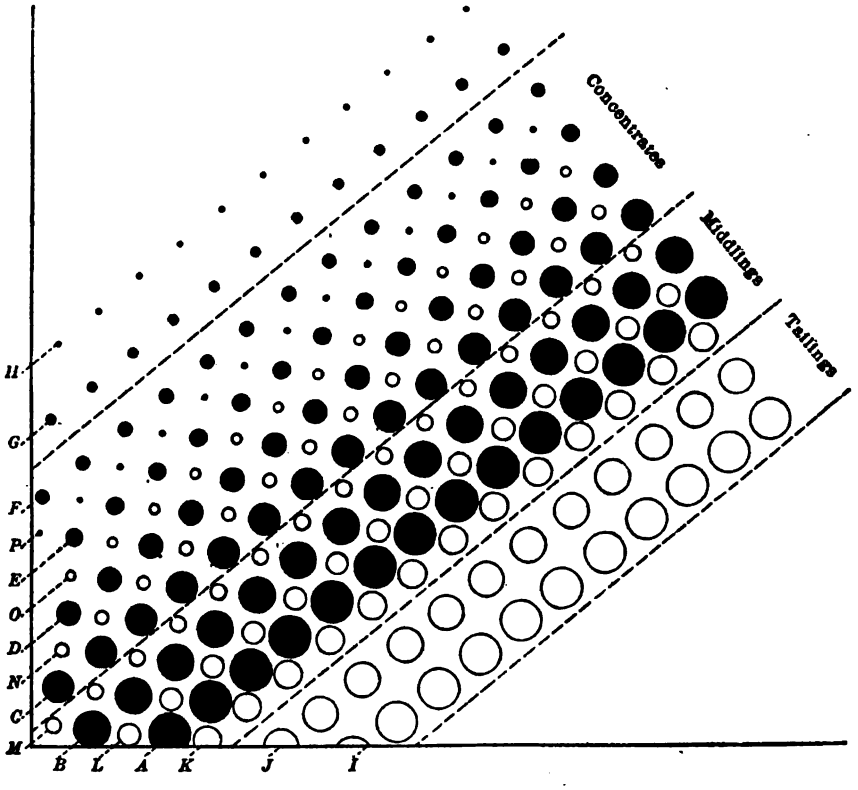

FIG. 4.—IDEAL SKETCH OF THE ARRANGEMENT OF GRAINS BY A WILFLEY TABLE

trates or the tailings. They have, however, some very interesting features that are worthy of note. The galena in the twelfth run runs high in the coarse and in the fine, and very low in the middle sizes, there being a great heaping up of quartz in this part. This same point is true in the sixteenth and seventeenth runs to a very marked degree. It is again true to a less marked degree in the fourteenth and fifteenth runs, and it appears not to be true at all in the thirteenth run.

Looking at the tailings (Table XV), we see that run No. 12 stands

out preëminent, having only 0.29 per cent. of galena in the whole tailings, and the tailings of runs Nos. 13 to 17 are very low in galena, and would probably pass in any concentrating establishment.

We have one feature here which does not and cannot happen in sized runs, Nos. 6 to 11—viz., the tailings get richer in galena down to the finer sizes; but when we look at the tonnage we find that there is scarcely any weight of material down in those sizes, and therefore this loss is not serious and does not bring up the percentage of galena in the final tailings to a serious extent.

Figure 4 is an ideal sketch of what happens at the discharging corner of a Wilfley table. Running from coarse on the lower edge to fine on the upper, *A, B, C, D, E, F, G,* and *H* represent the different sizes of galena. It appears that they arrange themselves approximately according to this order on the Wilfley table. In like manner, the quartz grains arrange themselves approximately in order of size, beginning at the lower edge with the largest grade and running smaller and smaller upwards, as indicated by the letters *I, J, K, L, M, N, O,* and *P*. The slimes at once take off the galena (*H*), and the quartz (*P*). These finest of all grains have not sufficient weight to hold them up to the upper edge, where mathematical logic would place them. They therefore go into the slimes. The next grade, *G* (galena), and *O* (quartz), are not fine enough to go into the slimes nor coarse enough to stand up against the water current in the position shown in the sketch. These grains are found, therefore, sprinkled through the concentrates, middlings, and tailings. See the heaping up of galena in the small sizes in Tables VIII, IX, and X.

TABLE VIII — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Concentrates sized and weighed. The weights are computed in tons and fractions of a ton on the 100-ton basis.

Sizes.		Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Through.	On.					
mm.	mm.	Ton.	Ton.	Ton.	Ton.	Ton.
. .	2.06	0.017	. .	. .	. .	0.009
2.06	1.63	0.050	. .	. .	. .	0.037
1.63	1.44	0.066	. .	. .	. .	0.054
1.44	1.27	0.112	. .	. .	. .	0.076
1.27	1.10	0.084	. .	. .	. .	0.049
1.10	0.97	0.120	0.003	. .	. .	0.079
0.97	0.84	0.174	0.012	. .	. .	0.104
0.84	0.68	0.206	0.027	. .	. .	0.128
0.68	0.57	0.245	0.048	. .	. .	0.138
0.57	0.45	0.506	0.280	0.225	. .	0.288
0.45	0.36	0.402	0.141	0.322	. .	0.201
0.36	0.28	0.445	0.465	1.000	0.227	0.308
0.28	0.24	0.306	0.304	0.386	0.061	0.179
0.24	0.20	0.375	0.370	0.586	0.760	0.230
0.20	0.15	0.307	0.324	0.483	0.997	0.218
0.15	0.12	0.209	0.313	0.483	0.958	0.213
0.12	0.10	0.110	0.207	0.271	0.397	0.082
0.10	0.08	0.189	0.235	0.404	0.871	0.229
0.08	0.00	0.182	0.244	0.507	1.052	0.191
Total tons		4.114	2.973	4.667	5.343	2.808

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Sizes.		Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
Through.	On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
. .	2.06	100.00	0.00	. .	. .	. .	. .	. .	. .	100.00	0.00
2.06	1.63	99.77	0.23	. .	. .	. .	. .	. .	. .	97.56	2.44
1.63	1.44	99.80	0.20	. .	. .	. .	. .	. .	. .	100.00	0.00
1.44	1.27	99.88	0.12	. .	. .	. .	. .	. .	. .	99.87	0.13
1.27	1.10	99.76	0.24	. .	. .	. .	. .	. .	. .	99.29	0.71
1.10	0.97	99.43	0.57	100.00	0.00	. .	. .	. .	. .	99.28	0.72
0.97	0.84	98.42	1.58	99.72	0.28	. .	. .	. .	. .	99.80	0.20
0.84	0.68	96.54	3.46	99.90	0.10	. .	. .	. .	. .	99.55	0.45
0.68	0.57	94.47	5.53	100.00	0.00	. .	. .	. .	. .	99.52	0.48
0.57	0.45	91.05	8.95	100.00	0.00	99.61	0.39	. .	. .	97.67	2.33
0.45	0.36	83.81	16.19	99.81	0.19	99.71	0.29	. .	. .	93.34	6.66
0.36	0.28	81.24	18.76	99.74	0.26	99.48	0.52	96.56	3.44	89.24	10.76
0.28	0.24	81.01	18.99	99.16	0.84	99.36	0.64	96.67	3.33	86.20	13.80
0.24	0.20	84.39	15.61	98.25	1.75	97.81	2.19	99.24	0.76	88.21	11.79
0.20	0.15	89.48	10.52	98.02	1.98	93.14	6.86	98.54	1.46	92.92	7.08
0.15	0.12	95.08	4.92	98.78	1.22	92.62	7.38	96.84	3.16	97.52	2.48
0.12	0.10	95.08	4.92	99.32	0.68	95.35	4.65	95.54	4.46	99.03	0.97
0.10	0.08	97.74	2.26	99.57	0.43	98.71	1.29	96.66	3.34	99.65	0.35
0.08	0.00	99.45	0.55	99.62	0.38	99.40	0.60	98.72	1.28	99.63	0.37
Concentrates before sizing		90.08	9.92	91.50	8.50	97.60	2.40	97.73	2.27	95.34	4.66

TABLE IX — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Middlings sized and weighed and the weights computed in tons and fractions of a ton on the 100-ton basis.

Size. On.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.
2.06	0.132	. .	. .	. .	0.206
1.63	0.795	. .	. .	. .	1.595
1.44	0.783	. .	. .	. .	2.134
1.27	1.202	. .	. .	. .	2.986
1.10	0.954	. .	. .	. .	2.438
0.97	1.056	0.292	. .	. .	3.178
0.84	1.552	1.330	. .	. .	4.793
0.68	2.021	0.329	. .	. .	5.113
0.57	1.865	1.350	. .	. .	4.323
0.45	3.112	3.208	2.171	. .	8.871
0.36	2.326	2.680	3.117	. .	3.144
0.28	2.526	3.945	5.955	0.402	3.655
0.24	0.848	1.436	4.805	1.684	1.079
0.20	1.230	2.932	3.696	4.729	0.969
0.15	0.648	1.551	4.262	4.713	0.581
0.12	0.207	0.893	0.481	3.660	0.223
0.10	0.075	0.299	0.418	2.296	0.050
0.08	0.061	0.286	0.601	2.216	0.054
0.00	0.093	0.224	0.373	1.328	0.146
Total tons . .	21.486	20.750	25.981	21.028	45.538

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	73.47	26.53	. .	. .	. .	. .	. .	. .	38.43	61.57
1.63	75.39	24.61	. .	. .	. .	. .	. .	. .	41.68	58.32
1.44	69.47	30.53	. .	. .	. .	. .	. .	. .	30.21	69.79
1.27	62.80	37.20	. .	. .	. .	. .	. .	. .	22.69	77.31
1.10	54.75	45.25	. .	. .	. .	. .	. .	. .	18.04	81.96
0.97	43.80	56.20	90.46	9.54	. .	. .	. .	. .	13.85	86.15
0.84	31.40	68.60	89.46	10.54	. .	. .	. .	. .	11.43	88.57
0.68	20.10	79.90	81.60	18.40	. .	. .	. .	. .	9.92	90.08
0.57	16.70	83.30	69.23	30.77	. .	. .	. .	. .	9.60	90.40
0.45	11.30	88.70	37.50	62.50	66.66	33.34	. .	. .	9.07	90.93
0.36	8.11	91.89	20.22	79.78	23.67	76.33	. .	. .	8.40	91.60
0.28	6.44	93.56	12.81	87.19	14.10	85.90	29.43	70.57	8.36	91.64
0.24	4.92	95.08	8.41	91.59	6.60	93.40	19.74	80.26	7.75	92.25
0.20	3.68	96.32	7.26	92.74	5.16	94.84	11.78	88.22	8.27	91.73
0.15	4.44	95.56	5.36	94.64	5.01	94.99	8.25	91.75	10.20	89.80
0.12	6.65	93.35	4.49	95.51	6.56	93.44	7.10	92.90	17.39	82.61
0.10	7.26	92.74	7.45	92.55	6.46	93.54	6.81	93.19	26.88	73.12
0.08	32.23	67.77	11.72	88.28	10.24	89.76	9.22	90.78	58.90	41.10
0.00	90.46	9.54	48.33	51.67	70.76	29.24	51.84	48.16	90.87	9.13
Middlings before sizing	23.58	76.42	26.63	73.37	15.90	84.10	12.84	87.16	13.71	86.29

TABLE X — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Tailings sized and weighed and the weights computed in tons and fractions of a ton on the 100-ton basis.

Size. On.	Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.
2.06	3.777	. .	. .	. .	2.003
1.63	14.713	. .	. .	. .	11.883
1.44	11.145	. .	. .	. .	9.065
1.27	8.085	. .	. .	. .	10.600
1.10	6.174	. .	. .	. .	4.294
0.97	7.322	11.860	. .	. .	4.452
0.84	5.191	16.217	. .	. .	1.489
0.68	3.350	8.821	. .	. .	0.682
0.57	2.078	5.789	. .	. .	0.405
0.45	2.501	11.639	20.635	. .	0.396
0.36	1.581	4.167	11.120	. .	0.162
0.28	1.056	3.315	10.790	0.400	0.456
0.24	0.523	0.915	2.829	2.019	0.303
0.20	0.633	2.341	3.277	12.345	0.680
0.15	0.739	1.860	3.574	11.948	1.075
0.12	1.139	1.781	4.308	9.015	0.507
0.10	0.624	1.067	1.113	6.118	0.614
0.08	0.948	1.461	2.965	9.778	0.878
0.00	1.277	1.670	2.202	8.864	0.742
Total tons . .	72.856	72.903	62.813	60.487	50.686

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	0.40	99.60	. .	. .	. .	. .	. .	. .	0.00	100.00
1.63	0.40	99.60	. .	. .	. .	. .	. .	. .	0.00	100.00
1.44	0.50	99.50	. .	. .	. .	. .	. .	. .	0.00	100.00
1.27	0.20	99.80	. .	. .	. .	. .	. .	. .	0.05	99.95
1.10	0.01	99.99	. .	. .	. .	. .	. .	. .	0.02	99.98
0.97	0.02	99.98	0.02	99.98	. .	. .	. .	. .	0.02	99.98
0.84	0.00	100.00	0.01	99.99	. .	. .	. .	. .	0.03	99.97
0.68	0.00	100.00	0.00	100.00	. .	. .	. .	. .	0.01	99.99
0.57	0.00	100.00	0.00	100.00	. .	. .	. .	. .	0.08	99.92
0.45	0.00	100.00	0.00	100.00	0.00	100.00	. .	. .	0.05	99.95
0.36	0.08	99.92	0.12	99.88	0.16	99.84	. .	. .	0.68	99.32
0.28	0.12	99.88	0.16	99.84	0.64	99.36	2.95	97.05	0.80	99.20
0.24	0.69	99.31	0.26	99.74	2.03	97.97	0.41	99.59	0.74	99.26
0.20	1.24	98.76	0.80	99.20	1.19	98.81	0.69	99.31	0.82	99.18
0.15	1.45	98.55	1.40	98.60	1.49	98.51	1.00	99.00	0.76	99.24
0.12	1.82	98.18	1.89	98.11	1.65	98.35	1.26	98.74	1.16	98.84
0.10	2.88	97.12	1.69	98.31	1.60	98.40	1.76	98.24	1.71	98.29
0.08	3.43	96.57	2.60	97.40	1.51	98.49	1.49	98.51	3.00	97.00
0.00	17.50	82.50	17.85	82.15	8.55	91.45	4.28	95.72	12.17	87.83
Tailings before sizing	0.51	99.49	0.61	99.39	0.90	99.10	1.61	98.39	0.29	99.71

TABLE XI — PROPORTION OF QUARTZ AND GALENA IN PRODUCTS

NOTE. — Slimes sized and weighed. The weights are computed in tons and parts of a ton, on the 100-ton basis.

Sizes.		Run No. 1.	Run No. 2.	Run No. 3.	Run No. 4.	Run No. 5.
Through.	On.					
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.
0.45	0.36	0.156	. .	. .	. .	. .
0.36	0.28	0.047	. .	. .	0.214	0.003
0.28	0.24	0.036	. .	. .	0.026	0.004
0.24	0.20	0.053	0.032	. .	0.044	0.007
0.20	0.15	0.063	0.072	0.207	0.091	0.027
0.15	0.12	0.052	0.062	0.078	0.138	0.037
0.12	0.10	0.068	0.149	0.241	1.515	0.038
0.10	0.08	0.134	0.446	1.662	1.268	0.244
0.08	0.00	0.935	2.613	4.351	9.846	0.606
Total tons		1.544	3.374	6.539	13.142	0.966

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Sizes.		Run No. 1.		Run No. 2.		Run No. 3.		Run No. 4.		Run No. 5.	
Through.	On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
0.45	0.36	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
0.36	0.28	10.20	89.80	. .	. .	. .	. .	48.54	51.46	18.30	81.70
0.28	0.24	10.00	90.00	. .	. .	. .	. .	54.55	45.45	15.40	84.60
0.24	0.20	10.81	89.19	14.04	85.96	. .	. .	40.22	59.78	11.80	88.20
0.20	0.15	12.58	87.42	7.94	92.06	45.21	54.79	37.16	62.84	8.10	91.90
0.15	0.12	19.00	81.00	7.26	92.74	21.21	78.79	28.96	71.04	6.50	93.50
0.12	0.10	24.28	75.72	7.19	92.81	17.53	82.47	9.37	90.63	5.00	95.00
0.10	0.08	27.04	72.96	5.03	94.97	8.53	91.47	6.87	93.13	6.40	93.60
0.08	0.00	28.31	71.69	10.72	89.28	11.53	88.47	8.76	91.24	19.40	80.60
Slimes before sizing		18.90	81.10	9.71	90.29	12.18	87.82	9.96	90.04	14.62	85.38

TABLE XII — RESULTS OF RUNS NOS. 6 TO 11 COMPUTED TO FULL SIZE

NOTE. — The weights of products have been computed in tons and fractions thereof.

	Run No. 6.	Run No. 7.	Run No. 8.	Run No. 9.	Run No. 10.	Run No. 11.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Concentrates	6.537	9.728	12.064	12.168	12.171	15.137
Middlings	1.647	1.901	1.694	1.602	5.310	3.170
Tailings	91.816	88.371	86.242	85.230	82.519	81.693
Slimes	0.000	0.000	0.000	0.000	0.000	0.000
Total	100.000	100.000	100.000	100.000	100.000	100.000

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

	Run No. 6.		Run No. 7.		Run No. 8.		Run No. 9.		Run No. 10.		Run No. 11.	
	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Concentrates	99.23	0.77	99.23	0.77	99.01	0.99	97.50	2.50	99.31	0.69	97.86	2.14
Middlings	59.67	40.33	23.10	76.90	17.00	83.00	22.60	77.40	19.97	80.03	15.35	84.65
Tailings	0.04	99.96	0.00	100.00	0.09	99.91	0.35	99.65	0.24	99.76	0.44	99.56
Slimes	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .

TABLE XIII — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The concentrates have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Sizes.		Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
Through.	On.						
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
. .	2.06	0.128	. .	. .	. .	. .	. .
2.06	1.63	4.869	0.001	0.0003	. .	. .	. .
1.63	1.44	6.331	0.001	0.0008	. .	. .	. .
1.44	1.27	7.861	0.002	0.0008	. .	. .	. .
1.27	1.10	4.455	0.002	0.0002	0.0005	. .	. .
1.10	0.96	4.093	0.002	0.0008	0.0003	. .	. .
0.96	0.84	5.837	0.011	0.001	0.0008	0.0005	. .
0.84	0.68	3.674	0.036	0.002	0.0005	0.0005	0.0004
0.68	0.57	3.615	0.124	0.006	0.001	0.001	0.0004
0.57	0.45	4.347	0.730	0.054	0.005	0.004	0.0023
0.45	0.36	2.063	1.208	0.174	0.012	0.007	0.004
0.36	0.28	1.232	0.687	0.656	0.060	0.049	0.015
0.28	0.24	0.445	0.384	0.415	0.110	0.077	0.015
0.24	0.20	0.330	0.393	0.697	0.332	0.138	0.057
0.20	0.15	0.152	0.223	0.701	1.176	0.220	0.108
0.15	0.12	0.088	0.084	0.393	1.321	0.634	0.086
0.12	0.10	0.029	0.021	0.143	0.551	0.748	0.109
0.10	0.08	0.055	0.029	0.104	1.057	2.300	0.934
0.08	0.00	0.045	0.012	0.052	0.315	1.539	3.650
Total tons		49.649	3.950	3.398	4.940	5.717	4.980

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.06	100.00	0.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
1.63	99.96	0.04	100.00	0.00	60.00	40.00	. .	. .	. .	. .	. .	. .
1.44	99.96	0.04	100.00	0.00	75.00	25.00	. .	. .	. .	. .	. .	. .
1.27	99.95	0.05	93.10	6.90	75.00	25.00	. .	. .	. .	. .	. .	. .
1.10	99.84	0.16	91.45	8.55	85.71	14.29	0.00	100.00	. .	. .	. .	. .
0.96	99.69	0.31	89.69	10.31	80.00	20.00	87.50	12.50	. .	. .	. .	. .
0.84	99.45	0.55	95.63	4.37	98.13	1.87	85.72	14.28	0.00	100.00	. .	. .
0.68	99.03	0.97	96.15	3.85	97.58	2.42	50.00	50.00	63.63	36.37	50.00	50.00
0.57	98.76	1.24	97.49	2.51	97.75	2.25	50.00	50.00	88.24	11.76	33.33	66.67
0.45	97.80	2.20	98.01	1.99	96.06	3.94	73.36	26.64	88.78	11.22	93.80	6.20
0.36	97.05	2.95	98.80	1.20	96.58	3.42	20.50	79.50	92.53	7.47	96.52	3.48
0.28	96.96	3.04	98.24	1.76	98.02	1.98	95.84	4.16	93.54	6.46	98.20	1.80
0.24	96.85	3.15	98.96	1.04	98.57	1.43	97.46	2.54	97.44	2.56	98.58	1.42
0.20	97.51	2.49	99.35	0.65	99.05	0.95	98.93	1.07	96.37	3.63	99.36	0.64
0.15	97.51	2.49	99.58	0.42	99.42	0.58	99.46	0.54	96.41	3.59	99.19	0.81
0.12	98.88	1.12	99.81	0.19	99.80	0.20	99.76	0.24	97.14	2.86	97.56	2.44
0.10	97.77	2.23	99.82	0.18	99.88	0.12	99.83	0.17	98.37	1.63	96.92	3.08
0.08	97.71	2.29	99.83	0.17	99.86	0.14	99.86	0.14	99.31	0.69	99.30	0.70
0.00	96.86	3.14	99.64	0.36	99.88	0.12	99.84	0.16	99.84	0.16	99.86	0.14
Concentrates before sizing	99.26	0.74	98.62	1.38	98.85	1.15	98.35	1.65	98.84	1.16	99.62	0.38

TABLE XIV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The middlings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Sizes. Through.	Sizes. On.	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
. .	2.49	0.005	. .	. .	. .	. .	. .
2.49	2.06	0.061	0.001	. .	. .	. .	. .
2.06	1.63	0.788	0.015	0.002	. .	. .	. .
1.63	1.44	0.602	0.026	0.001	. .	. .	. .
1.44	1.27	0.951	0.037	0.002	. .	. .	. .
1.27	1.10	0.676	0.014	0.002	. .	. .	. .
1.10	0.96	0.605	0.018	0.002	0.0003	. .	. .
0.96	0.84	0.758	0.078	0.005	0.0003	0.001	. .
0.84	0.68	0.473	0.120	0.011	0.002	0.001	0.001
0.68	0.57	0.263	0.194	0.033	0.003	0.003	0.001
0.57	0.45	0.234	0.494	0.092	0.020	0.011	0.003
0.45	0.36	0.042	0.188	0.133	0.031	0.025	0.004
0.36	0.28	0.030	0.089	0.236	0.139	0.064	0.075
0.28	0.24	0.015	0.014	0.048	0.093	0.070	0.080
0.24	0.20	0.011	0.011	0.068	0.250	0.213	0.281
0.20	0.15	0.004	0.003	0.020	0.146	0.299	0.809
0.15	0.12	0.004	0.002	0.005	0.076	0.188	1.013
0.12	0.10	0.001	0.001	0.001	0.015	0.051	0.531
0.10	0.08	0.004	0.001	0.001	0.028	0.060	0.909
0.08	0.00	0.007	0.001	0.001	0.025	0.057	0.555
Total tons		5.534	1.307	0.663	0.828	1.043	4.262

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.06	22.34	77.66	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
1.63	31.80	68.20	8.84	91.16	68.18	31.82	. .	. .	. .	. .	. .	. .
1.44	25.40	74.60	10.87	89.13	55.55	44.45	. .	. .	. .	. .	. .	. .
1.27	17.70	82.30	21.33	78.67	31.82	68.18	. .	. .	. .	. .	. .	. .
1.10	7.93	92.07	28.29	71.71	41.40	58.60	. .	. .	. .	. .	. .	. .
0.96	6.73	93.27	39.39	60.61	33.33	66.67	16.67	83.33	. .	. .	. .	. .
0.84	4.04	95.96	38.92	61.08	44.45	55.55	16.67	83.33	66.67	33.33	. .	. .
0.68	3.10	96.90	29.42	70.58	42.44	57.56	59.45	40.55	23.08	76.92	64.29	35.71
0.57	2.43	97.57	25.14	74.86	37.50	62.50	61.54	38.46	66.67	33.33	52.39	47.61
0.45	3.56	96.44	31.00	69.00	38.80	61.20	62.27	37.73	79.58	20.42	75.52	24.48
0.36	5.58	94.42	47.93	52.07	38.58	61.42	59.76	40.24	47.72	52.28	83.34	16.66
0.28	9.57	90.43	49.53	50.47	32.44	67.56	33.33	66.67	28.51	71.49	28.17	71.83
0.24	16.15	83.85	46.20	53.80	28.12	71.88	18.51	81.49	11.15	88.85	10.67	89.33
0.20	22.80	77.20	52.99	47.01	26.72	73.28	18.45	81.55	5.86	94.14	4.60	95.40
0.15	27.33	72.67	71.90	28.10	32.77	67.23	16.93	83.07	4.91	95.09	2.25	97.75
0.12	95.98	4.02	88.22	11.78	42.00	58.00	23.79	76.21	6.27	93.73	3.54	96.46
0.10	96.91	3.09	92.04	7.96	60.78	39.22	41.44	58.56	11.32	88.68	5.10	94.90
0.08	97.92	2.08	91.95	8.05	74.16	25.84	79.81	20.19	40.12	59.88	11.12	88.88
0.00	98.06	1.94	96.40	3.60	6.32	93.68	98.07	1.93	90.42	9.58	82.98	17.02
Middlings before sizing .	13.85	86.15	33.95	66.05	34.43	65.57	28.90	71.10	16.25	83.75	16.28	83.72

TABLE XV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The tailings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Size. On.	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
2.49	0.042	0.043	. .	. .	. .	. .
2.06	1.762	1.336	0.056	0.027	. .	. .
1.63	18.040	18.429	2.083	0.023	. .	0.016
1.44	10.232	21.674	4.434	0.017	0.016	0.011
1.27	8.176	20.207	11.129	0.030	0.016	0.011
1.10	2.828	11.066	9.834	0.071	0.016	0.011
0.96	1.590	7.877	8.167	0.185	0.021	0.022
0.84	1.457	7.835	13.670	0.780	0.026	0.016
0.68	0.281	2.076	13.131	1.843	0.047	0.033
0.57	0.178	2.098	11.080	7.316	0.163	0.044
0.45	0.103	1.122	14.410	21.851	2.381	1.945
0.36	0.021	0.121	4.532	20.371	5.709	5.423
0.28	0.019	0.097	2.604	30.530	34.072	31.480
0.24	0.015	0.038	0.437	5.486	17.393	17.182
0.20	0.017	0.024	0.220	4.473	18.103	19.917
0.15	0.012	0.019	0.087	0.790	10.150	10.175
0.12	0.015	0.014	0.033	0.240	3.129	2.845
0.10	0.002	0.009	0.010	0.084	1.249	0.911
0.08	0.010	0.029	0.010	0.071	0.580	0.544
0.00	0.017	0.029	0.012	0.044	0.169	0.172
Total tons . .	44.817	94.743	95.939	94.232	93.240	90.758

ANALYSES OF THE ABOVE PRODUCTS, GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
2.06	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.63	0.00	100.00	0.08	99.92	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.44	0.52	99.48	0.07	99.93	0.09	99.91	0.00	100.00	0.00	100.00	0.00	100.00
1.27	0.20	99.80	0.48	99.52	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
1.10	0.38	99.62	0.09	99.91	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
0.96	0.67	99.33	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.84	0.74	99.26	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.68	0.76	99.24	0.54	99.46	0.02	99.98	0.00	100.00	1.10	98.90	. .	. .
0.57	1.20	98.80	1.16	98.84	0.02	99.98	0.00	100.00	0.32	99.68	0.00	100.00
0.45	1.03	98.97	6.04	93.96	0.10	99.90	0.17	99.83	0.86	99.14	1.36	98.64
0.36	1.28	98.72	16.00	84.00	0.84	99.16	0.23	99.77	0.45	99.55	0.69	99.31
0.28	7.08	92.92	33.05	66.95	2.08	97.92	0.98	99.02	0.17	99.83	0.34	99.66
0.24	9.22	90.78	27.60	72.40	3.88	96.12	0.27	99.73	0.30	99.70	0.58	99.42
0.20	5.64	94.36	19.00	81.00	5.21	94.79	0.43	99.57	0.35	99.65	0.55	99.45
0.15	5.90	94.10	13.32	86.68	7.73	92.27	3.30	96.70	0.44	99.56	0.54	99.46
0.12	7.50	92.50	15.30	84.70	9.59	90.41	8.97	91.03	0.87	99.13	1.01	98.99
0.10	5.40	94.60	40.40	59.60	72.79	27.21	17.32	82.68	1.83	98.17	2.07	97.93
0.08	28.38	71.62	55.55	44.45	21.43	78.57	26.55	73.45	7.04	92.96	7.38	92.62
0.00	85.93	14.07	87.00	13.00	68.68	31.32	68.32	31.68	42.36	57.64	44.28	55.72
Tailings before sizing	0.29	99.71	0.36	99.64	0.20	99.80	0.55	99.45	0.46	99.54	0.66	99.34

TABLE XIV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The middlings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Sizes. Through.	Sizes. On.	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
mm.	mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
. .	2.49	0.005	. .	. .	. .	. .	. .
2.49	2.06	0.061	0.001	. .	. .	. .	. .
2.06	1.63	0.788	0.015	0.002	. .	. .	. .
1.63	1.44	0.602	0.026	0.001	. .	. .	. .
1.44	1.27	0.951	0.037	0.002	. .	. .	. .
1.27	1.10	0.676	0.014	0.002	. .	. .	. .
1.10	0.96	0.605	0.018	0.002	0.0003	. .	. .
0.96	0.84	0.758	0.078	0.005	0.0003	0.001	. .
0.84	0.68	0.473	0.120	0.011	0.002	0.001	0.001
0.68	0.57	0.263	0.194	0.033	0.003	0.003	0.001
0.57	0.45	0.234	0.494	0.092	0.020	0.011	0.003
0.45	0.36	0.042	0.188	0.133	0.031	0.025	0.004
0.36	0.28	0.030	0.089	0.236	0.139	0.064	0.075
0.28	0.24	0.015	0.014	0.048	0.093	0.070	0.080
0.24	0.20	0.011	0.011	0.068	0.260	0.213	0.281
0.20	0.15	0.004	0.003	0.020	0.146	0.299	0.809
0.15	0.12	0.004	0.002	0.005	0.076	0.188	1.013
0.12	0.10	0.001	0.001	0.001	0.015	0.051	0.531
0.10	0.08	0.004	0.001	0.001	0.028	0.060	0.909
0.08	0.00	0.007	0.001	0.001	0.025	0.057	0.555
Total tons		5.534	1.307	0.663	0.828	1.043	4.202

ANALYSES OF THE ABOVE PRODUCTS GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
2.06	22.34	77.66	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
1.63	31.80	68.20	8.84	91.16	68.18	31.82	. .	. .	. .	. .	. .	. .
1.44	25.40	74.60	10.87	89.13	55.55	44.45	. .	. .	. .	. .	. .	. .
1.27	17.70	82.30	21.33	78.67	31.82	68.18	. .	. .	. .	. .	. .	. .
1.10	7.93	92.07	28.29	71.71	41.40	58.60	. .	. .	. .	. .	. .	. .
0.96	6.73	93.27	39.39	60.61	33.33	66.67	16.67	83.33	. .	. .	. .	. .
0.84	4.04	95.96	38.92	61.08	44.45	55.55	16.67	83.33	66.67	33.33	. .	. .
0.68	3.10	96.90	29.42	70.58	42.44	57.56	59.45	40.55	23.08	76.92	64.29	35.71
0.57	2.43	97.57	25.14	74.86	37.50	62.50	61.54	38.46	66.67	33.33	52.39	47.61
0.45	3.56	96.44	31.00	69.00	38.80	61.20	62.27	37.73	79.58	20.42	75.52	24.48
0.36	5.58	94.42	47.93	52.07	38.58	61.42	59.76	40.24	47.72	52.28	83.34	16.66
0.28	9.57	90.43	49.53	50.47	32.44	67.56	33.33	66.67	28.51	71.49	28.17	71.83
0.24	16.15	83.85	46.20	53.80	28.12	71.88	18.51	81.49	11.15	88.85	10.67	89.33
0.20	22.80	77.20	52.99	47.01	26.72	73.28	18.45	81.55	5.86	94.14	4.60	95.40
0.15	27.33	72.67	71.90	28.10	32.77	67.23	16.93	83.07	4.91	95.09	2.25	97.75
0.12	95.98	4.02	88.22	11.78	42.00	58.00	23.79	76.21	6.27	93.73	3.54	96.46
0.10	96.91	3.09	92.04	7.96	60.78	39.22	41.44	58.56	11.32	88.68	5.10	94.90
0.08	97.92	2.08	91.95	8.05	74.16	25.84	79.81	20.19	40.12	59.88	11.12	88.88
0.00	98.06	1.94	96.40	3.60	6.32	93.68	98.07	1.93	90.42	9.58	82.98	17.02
Middlings before sizing .	13.85	86.15	33.95	66.05	34.43	65.57	28.90	71.10	16.25	83.75	16.28	83.72

TABLE XV — RESULTS OF RUNS NOS. 12 TO 17 COMPUTED TO FULL SIZE

NOTE. — The tailings have been sized and weighed and the weights computed in tons and fractions thereof on the 100-ton basis.

Size. On.	Run No. 12.	Run No. 13.	Run No. 14.	Run No. 15.	Run No. 16.	Run No. 17.
mm.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
2.49	0.042	0.043	. .	. .	. .	. .
2.06	1.762	1.336	0.056	0.027	. .	. .
1.63	18.040	18.429	2.083	0.023	. .	0.016
1.44	10.232	21.674	4.434	0.017	0.016	0.011
1.27	8.176	20.207	11.129	0.030	0.016	0.011
1.10	2.828	11.066	9.834	0.071	0.016	0.011
0.96	1.590	7.877	8.167	0.185	0.021	0.022
0.84	1.457	7.835	13.670	0.780	0.026	0.016
0.68	0.281	2.676	13.131	1.843	0.047	0.033
0.57	0.178	2.098	11.080	7.316	0.163	0.044
0.45	0.103	1.122	14.410	21.851	2.381	1.945
0.36	0.021	0.121	4.532	20.371	5.709	5.423
0.28	0.019	0.097	2.604	30.530	34.072	31.480
0.24	0.015	0.038	0.437	5.486	17.393	17.182
0.20	0.017	0.024	0.220	4.473	18.103	19.917
0.15	0.012	0.019	0.087	0.790	10.150	10.175
0.12	0.015	0.014	0.033	0.240	3.129	2.845
0.10	0.002	0.009	0.010	0.084	1.249	0.911
0.08	0.010	0.029	0.010	0.071	0.580	0.544
0.00	0.017	0.029	0.012	0.044	0.169	0.172
Total tons . .	44.817	94.743	95.939	94.232	93.240	90.758

ANALYSES OF THE ABOVE PRODUCTS, GIVING PERCENTAGES OF GALENA (PbS) AND QUARTZ (SiO_2)

Size.	Run No. 12.		Run No. 13.		Run No. 14.		Run No. 15.		Run No. 16.		Run No. 17.	
On.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.	Galena.	Quartz.
mm.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
2.49	0.00	100.00	0.00	100.00	. .	. .	. .	. .	. .	. .	. .	. .
2.06	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.63	0.00	100.00	0.08	99.92	0.00	100.00	0.00	100.00	. .	. .	. .	. .
1.44	0.52	99.48	0.07	99.93	0.09	99.91	0.00	100.00	0.00	100.00	0.00	100.00
1.27	0.20	99.80	0.48	99.52	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
1.10	0.38	99.62	0.09	99.91	0.06	99.94	0.00	100.00	0.00	100.00	. .	. .
0.96	0.67	99.33	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.84	0.74	99.26	0.18	99.82	0.03	99.97	0.00	100.00	0.00	100.00	. .	. .
0.68	0.76	99.24	0.54	99.46	0.02	99.98	0.00	100.00	1.10	98.90	. .	. .
0.57	1.20	98.80	1.16	98.84	0.02	99.98	0.00	100.00	0.32	99.68	0.00	100.00
0.45	1.03	98.97	6.04	93.96	0.10	99.90	0.17	99.83	0.86	99.14	1.36	98.64
0.36	1.28	98.72	16.00	84.00	0.84	99.16	0.23	99.77	0.45	99.55	0.69	99.31
0.28	7.08	92.92	33.05	66.95	2.08	97.92	0.98	99.02	0.17	99.83	0.34	99.66
0.24	9.22	90.78	27.60	72.40	3.88	96.12	0.27	99.73	0.30	99.70	0.58	99.42
0.20	5.64	94.36	19.00	81.00	5.21	94.79	0.43	99.57	0.35	99.65	0.55	99.45
0.15	5.90	94.10	13.32	86.68	7.73	92.27	3.30	96.70	0.44	99.56	0.54	99.46
0.12	7.50	92.50	15.30	84.70	9.59	90.41	8.97	91.03	0.87	99.13	1.01	98.99
0.10	5.40	94.60	40.40	59.60	72.79	27.21	17.32	82.68	1.83	98.17	2.07	97.93
0.08	28.38	71.62	55.55	44.45	21.43	78.57	26.55	73.45	7.04	92.96	7.38	92.62
0.00	85.93	14.07	87.00	13.00	68.68	31.32	68.32	31.68	42.36	57.64	44.28	55.72
Tailings before sizing	0.29	99.71	0.36	99.64	0.20	99.80	0.55	99.45	0.46	99.54	0.66	99.34

Having laid out our argument in this way, it now remains for us to compare by means of this diagram runs Nos. 1 to 5, 6 to 11, and 12 to 17, and to see why it is that runs Nos. 6 to 11 and Nos. 12 to 17 are so much better than runs Nos. 1 to 5. Runs Nos. 1 to 5 take the products just as they are shown in Figure 4, and give galena, *C, D, E, F,* in the concentrates contaminated by quartz (*N*). See the heaping up of the quartz a little below the middle size in Table VIII, and the middlings that give quartz, *K, L,* and *M,* contaminated by galena, *A, B, C,* and *G*. See the heaping up of galena among the large grains and among the small grains in Table IX, and the tailings have in them the quartz, *I, J,* and *O,* contaminated by galena, *G*. See the heaping up of galena in the fine sizes in Table X. Runs Nos. 6 to 11, on the other hand, have put together on the coarse table, quartz, *I,* and galena, *A,* which have nothing whatever to do with one another (see Table XII), and therefore make almost 100 per cent. of galena in the concentrates, and almost 100 per cent. of quartz in the tailings. The little accidental middling product, simply being the dividing line between the two products, goes back on the table and disappears. On the second table we treat quartz, *J,* and galena, *B,* with the same result. On the third table we treat quartz, *K,* and galena, *C,* with the same result; on the fourth table quartz, *L,* and galena, *D;* on the fifth table quartz, *M,* and galena, *E;* on the sixth table quartz, *N,* and galena, *F*. There seems no reason logically why these should not turn out 100 per cent. of galena in the concentrates and 100 per cent. of quartz in the tailings. The probable reason why we did not obtain those figures was that the accidental flat scales and the fine abrasions of galena went where they should not.

Going to the third set of runs, Nos. 12 to 17, we need to bring in an ideal picture of the products of a classifier by means of Figure 5. Suppose, for example, that we drop into a tall tube of water grains of quartz ranging from our maximum size down to zero, and grains of galena in the same way, and that these grains are of approximately the same shape, then the rate of settling of these grains may be stated in the following terms: The larger grains of a single mineral will settle faster than the smaller grains; and when we compare the two gravities of quartz and galena, the higher gravity will settle faster than the lower gravity for the same size. So definite is this law, that if we look for equal-settling particles we shall find that the grain of quartz which is equal-settling with the grain of galena is about three

or four times the diameter of the grain of galena. See settling ratios in Table III. We may, therefore, construct the ideal diagram, Figure 5, and we can draw a set of horizontal lines across it, putting the equal-settling grains together, ranging from the heavier grains of the first spigot in the lower part of the diagram up to the lighter grains of the finer spigot at the upper part of the diagram. We see then

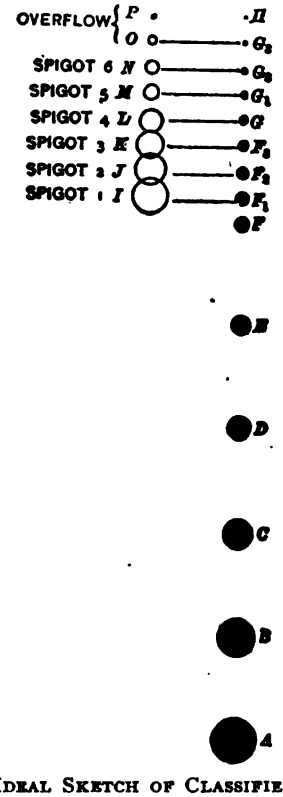

FIG. 5.—IDEAL SKETCH OF CLASSIFIER-PRODUCT

that spigot 1 contains a large amount of galena ranging from the coarsest size down to one-quarter the diameter of the coarsest quartz, and that the quartz is almost all in the coarse sizes. See spigot 1, Table III. This is exactly what we found in our run No. 12. See the heaping up of galena in the large sizes in Table XIII.

Spigot 2 has small galena and large quartz, but both are a little smaller than those in spigot 1. Spigot 3, again, has small galena and larger quartz, but a little smaller than spigot 2, and so on up the scale

with spigot 4, spigot 5, and spigot 6. See the heaping up of galena in smaller sizes, Table XIII, and of quartz in larger sizes in Table XV.

Looking at our diagram, Figure 4, to see what will happen when these several spigots are put upon the table, we shall find that run No. 12 receives galena, *A, B, C, D, E, F,* and *G,* and quartz, *I.* Logically these have nothing to do with one another, and therefore should make for perfect separation. Spigot 2 fed in run No. 13 would have quartz, *J,* and galena, F_2. Spigot 3 would have quartz, *K,* and galena, F_3, and so on. Spigots 4, 5, and 6 could work their way up, having quartz always larger, and therefore belonging at a lower place on the table, and galena of smaller diameter belonging at a higher place on the table, making for clean separation of concentrates and tailings, with a middling product that can go directly back on the table and disappear. In proof of this, see points of heaping up of galena and quartz in Tables XIII and XV.

In the light of Figure 4, comparing runs 12 to 17 with runs 6 to 11 we see that the natural lines for quartz and galena are farther apart for the classified products than for the sized products. For example, in run 12 the galena lines *A* to *F* average farther from the quartz *I* than does the galena *A* of run 6. Again, in run 13 the galena *F* is farther from quartz *J* than is the galena *B* from quartz *J* in run 7. In like manner we may compare classified runs 14, 15, 16, and 17 with sized runs 8, 9, 10, and 11.

This demonstrates that with perfect classification the work will be better done on the Wilfley table than with sizing, and it also shows that with much middle weight mineral or included grains a good classifier will probably be more efficient than screens.

Conclusions

1. The natural product as feed for a Wilfley table is completely outclassed and surpassed by sized-product feed and by classifier-product feed.

2. While the sized-product feed, as shown in Table VII, appears to have done better work than the classifier-product feed, if we give full weight to the great performance of run No. 12, we can agree that this has fully offset the slight falling off of runs Nos. 13 to 17, and that the classifier-feed work is fully up to the sized-feed work on the Wilfley table, and with a perfect classifier the work will be better done than with screens.

TENSION TESTS OF STEEL ANGLES WITH VARIOUS TYPES OF END-CONNECTION[1]

By FRANK P. McKIBBEN

THE tests which form the subject of this paper were made upon thirty-three steel angles, such as are used for tension members in riveted framed structures. They are a continuation of a series made at the Massachusetts Institute of Technology in 1906 (*Engineering News*, July 5, 1906, p. 14; TECHNOLOGY QUARTERLY, 19, No. 3, pp. 306–313). This series of tests (begun last year and not yet completed) has been undertaken with a view of studying the following points:

(1) The ultimate strength of the angles in tension.

(2) The value of a lug in transmitting stress from the outstanding leg of the main angle into the hitch plate.

(3) The relative strength of angles where the gauge line for rivets and where the centre of gravity line, respectively, pass through the centre of the pull.

(4) The effect of the position of the rivets connecting the main angles to the hitch plates.

(5) The relative strength of single angles and angles riveted together to form pairs.

(6) The effect upon the strength of the specimen of the different methods of holding the specimen in the testing machine.

In the series tested this year there are three specimens of each of ten different types, also three specimens which differ from one another and from one of the ten types only slightly. This makes thirty-three angles in all. These are shown in detail in Figure 1. Each of the main angles, 5 feet 4 inches in length, is riveted at each end to a hitch plate.

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[1] A paper read before the American Society for Testing Materials at Atlantic City, N. J., June 22, 1907. Reprinted from Engineering News, Aug. 22, 1907, 58, No. 8, pp. 190–192.

The description of the different types tested is as follows:

A_3: One 3½ × 3 × ⅜ inch angle, connected at each end by six rivets, three in each leg, with lugs; and with the gauge line passing through the centre of pull.

A_4: same as A_3, except with centre of gravity line, in plan, passing through centre of pull.

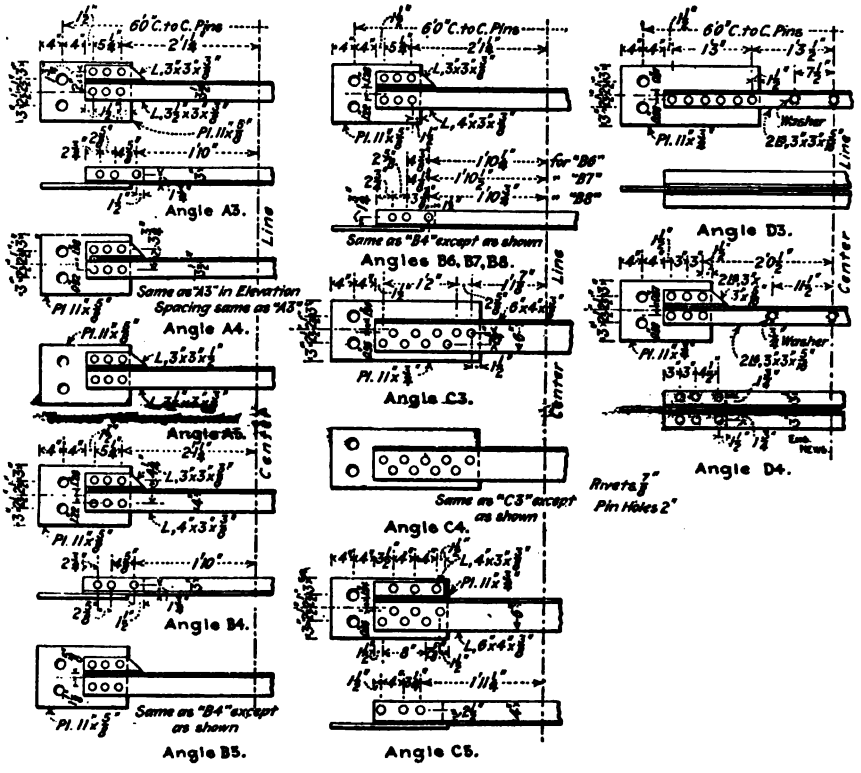

FIG. 1.—TEST SPECIMENS USED IN 1907 TESTS OF STEEL ANGLES

A_5: same as A_4, but with thicker lug angles.

B_4: similar to A_4, but with 4 × 3 × ⅜ inch main angles.

B_5: similar to B_4, but with centre of pull passing in plan ⅝ inch from back of vertical leg.

B_6, B_7, B_8: same as B_4, but with staggers between the two inner rivets decreasing successively by ¼ inch.

C_3: One 6 × 4 × ⅜ inch angle connected to each hitch plate by nine rivets staggered in two rows in the 6-inch leg, but with both inner

rivets on the gauge line nearest the back of the angle. Centre of gravity line passes through centre of pull.

C_4: same as C_3, except that the two inner rivets are staggered instead of on the same gauge line.

C_5: similar to C_4, but with lugs; six rivets in 6-inch leg and three rivets in 4-inch leg at each plate.

D_3: Two $3 \times 3 \times 3/8$ inch angles, one on each side of the hitch plate, and connected without lugs to each plate by six rivets all in one row. The centre of gravity line passes through centre of pull.

D_4: similar to D_3, but with lugs; each main angle is connected at either end with three rivets in each leg.

Improvements upon the types of connections used in the 1906 series of tests were attempted in the following ways: (1) By increasing the stagger between the two inner rivets, in cases where there were rivets in both legs of the angle, until the minimum net zigzag area of the angle through two rivets was at least equal to the net right section. (2) By placing the two inner rivets on the inner gauge line in specimens having two rows of rivets in the leg connecting with the hitch plate. (3) By applying the pull to the specimen through the centre of gravity line of the angle in plan. (4) By using thicker lug angles.

The connections of the angles to the hitch plates were so designed as to ensure failure in the angles rather than in the rivets or connecting plates. The hitch plate at each end of each specimen was provided with two 2-inch holes, by means of which it was pinned between two holding plates, which in turn were connected by a single pin to a third plate gripped by the testing machine. (*Engineering News*, July 5, 1906, page 14; TECHNOLOGY QUARTERLY, *l.c.*, Figure 2, page 30.) It should be borne in mind that the holding device is a flexible joint, and is not the rigid connection more commonly found in structures in which angles are used as tension members. The method of holding the ends has an important bearing on the strength of the angles, and the presence of this flexible joint should not be lost sight of in studying the results of the tests thus far made. The writer hopes to make further tests in which a rigid connection is to be used.

Table I gives the results of the physical tests of small tensile test bars which were cut from the long angles, out of which were taken the main angles of the specimens tested this year. In most cases three such test bars were taken from each long angle, but in two cases only two bars were secured from each long angle. On all of these test

pieces the yield point was determined by the drop of the beam and also by measurement with dividers.

TABLE I — PHYSICAL PROPERTIES OF SMALL TEST BARS CUT FROM STEEL ANGLES USED IN 1907 TESTS

Test piece.	Yield point.	Ultimate strength.	Elongation.	Reduction of area.
	Lbs. per sq. in.	Lbs. per sq. in.	Per cent. in 8 in.	Per cent.
AA3, AA4	35,500	57,900	29.1	57.0
	35,500	57,800	28.6	53.3
	35,300	57,600	28.6	54.7
Mean	35,400	57,800	28.8	55.0
AA5	36,100	56,500	29.6	56.3
	34,700	56,600	29.0	54.5
	34,700	56,500	28.9	49.7
Mean	35,200	56,500	29.2	53.5
BB4, BB5, BB7	35,000	53,500	29.2	58.6
	34,300	53,400	31.9	59.3
	35,100	54,000	30.9	58.2
Mean	34,800	53,600	30.7	58.7
BB6, BB8	35,400	59,500	27.0	50.4
	33,700	60,000	28.0	48.6
	36,900	59,900	27.4	54.4
Mean	35,300	59,800	27.5	51.1
CC3, CC4, CC5	36,900	59,800	31.3	55.2
	37,600	59,300	27.1	57.1
	38,400	59,600	27.9	54.7
Mean	37,600	59,600	28.8	55.7
DD3	39,000	60,200	25.9	49.3
	38,900	59,600	26.8	51.2
Mean	39,000	59,900	26.4	50.3
DD4	38,400	58,800	30.3	50.8
	39,100	58,800	28.5	56.5
Mean	38,800	58,800	29.4	53.7

NOTE. — The test pieces were approximately ½ square inch in cross-section (0.455 to 0.573 square inch).

In Figure 2 are shown diagrammatically the outlines of the fractures, all of which occurred in the main angles. The numbers on the sketches indicate the sequence of the ruptures. With the exception of specimen 57, made of two $3 \times 3 \times \frac{5}{16}$ inch angles, failure occurred at one of the inner rivets which connects the main angle to the hitch plate, that is, the connecting rivet which lies nearest to the centre of the specimen. In the case of specimen 57 one of the angles failed at the inner connecting rivet, but the other angle failed at the first tack rivet 8 inches from the inner rivet. In every case the fracture started at a rivet. In the majority of cases of specimens having lugs failure occurred on a zigzag section passing through rivets in the horizontal and in the vertical legs. This was the case, even though the minimum net zigzag section was slightly larger than the net right section, as, for example, specimens 31, 32, 33. In some of the specimens having

the two net sections just mentioned nearly equal, for instance specimens 35 and 37, the fracture really occurred on the zigzag section, but it also started on the right section. Failure occurred on the right section in some cases. In many specimens the angle failed by shearing on the diagonal section between the inner rivets in the horizontal and in the vertical legs after the metal between these rivets and the outer edges of the legs had been broken. The fractures were all silky. In specimen 50 a slight flaw was detected after failure at the inner rivet

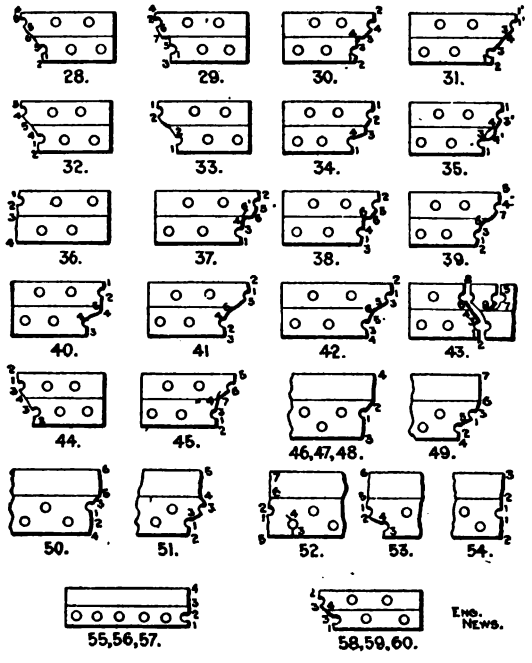

FIG. 2.—SKETCHES OF STEEL ANGLES HAVING VARIOUS TYPES OF END-CONNECTION

in the leg attached to the plate. The specimens made of two angles failed more suddenly than those made of one.

Table II is a summary of the tests of the specimens. Nos. 1 to 27, inclusive, are those tested in 1906 and previously published, and Nos. 28 to 60, inclusive, are those tested this year. The figures in the columns headed "Per Cent. of Ultimate Strength Developed" are obtained by dividing the strength per square inch in the specimen by the ultimate strength per square inch of the small test bars and multiplying by 100 to reduce to a percentage basis. Net areas have been

TABLE II — Summary of Tension Tests of Steel Angles, 1906 and 1907

1906 Tests.			Areas in Square Inches.					Total breaking load in pounds.	Breaking Loads in Pounds per Square Inch.					Per Cent. of Ultimate Strength Developed.*				
Type.	No. of specimen.	Nominal dimensions.	Actual gross.	Net right. 13/16″ holes.	Net right. 1″ holes.	Least net zigzag. 13/16″ holes.	Least net zigzag. 1″ holes.		Actual gross area.	Net right section. 13/16″ holes.	Net right section. 1″ holes.	Least net zigzag. 13/16″ holes.	Least net zigzag. 1″ holes.	Actual gross area.	Net right section. 13/16″ holes.	Net right section. 1″ holes.	Least net zigzag. 13/16″ holes.	Least net zigzag. 1″ holes.
A1	1	3½″ × 3″ × ⅜″	2.29	1.95	1.93	. .	. .	89,500	39,100	45,900	46,400	. .	. .	65.9	77.4	78.3	. .	. .
	2		2.32	1.97	1.95	. .	. .	96,100	41,400	48,800	49,300	. .	. .	69.8	82.3	83.2	. .	. .
	3		2.35	2.00	1.98	. .	. .	95,200	40,500	47,600	48,100	. .	. .	68.3	80.3	81.1	. .	. .
	Mean		2.32	1.97	1.95	. .	. .	93,600	40,300	47,400	47,900	. .	. .	68.0	80.0	80.9	. .	. .
A2	4	3½″ × 3″ × ⅜″	2.28	1.94	1.92	1.67	1.63	84,600	37,100	43,600	44,000	50,600	51,900	62.5	73.6	74.3	85.4	87.6
	5		2.31	1.97	1.94	1.69	1.64	88,600	38,300	45,000	45,600	52,400	54,000	64.5	76.0	77.0	88.4	91.1
	6		2.27	1.93	1.91	1.66	1.61	91,200	40,200	47,200	47,700	54,900	56,600	67.8	79.6	80.5	92.7	95.5
	Mean		2.29	1.95	1.92	1.67	1.63	88,100	38,500	45,300	45,800	52,600	54,200	64.9	76.4	77.3	88.8	91.4
B1	7	4″ × 3″ × ⅜″	2.43	2.10	2.07	. .	. .	85,000	35,000	40,500	41,100	. .	. .	64.8	75.0	76.1	. .	. .
	8		2.42	2.09	2.06	. .	. .	84,000	34,700	40,200	40,800	. .	. .	64.2	74.5	75.6	. .	. .
	9		2.50	2.15	2.13	. .	. .	85,600	34,200	39,800	40,200	. .	. .	63.3	73.7	74.5	. .	. .
	Mean		2.45	2.11	2.09	. .	. .	84,900	34,600	40,200	40,700	. .	. .	64.1	74.4	75.4	. .	. .
B2	10	4″ × 3″ × ⅜″	2.42	2.09	2.06	1.82	1.76	83,500	34,500	39,900	40,500	45,900	47,400	63.9	73.9	75.0	85.0	87.8
	11		2.43	2.09	2.07	1.81	1.76	85,100	35,000	40,700	41,100	47,000	48,400	64.8	75.4	76.1	87.1	89.7
	12		2.45	2.11	2.08	1.86	1.81	84,100	34,300	39,900	40,400	45,200	46,500	63.5	73.9	74.8	83.7	86.1
	Mean		2.43	2.10	2.07	1.83	1.78	84,200	34,600	40,200	40,700	46,000	47,400	64.1	74.4	75.3	85.3	87.9
B3	13	4″ × 3″ × ⅜″	2.40	2.07	2.04	. .	. .	88,600	36,900	42,800	43,400	. .	. .	68.3	79.3	80.3	. .	. .
	14		2.42	2.09	2.06	. .	. .	90,400	37,300	43,200	43,800	. .	. .	69.0	80.0	81.1	. .	. .
	15		2.41	2.07	2.05	. .	. .	91,000	37,800	44,000	44,400	. .	. .	70.0	81.5	82.2	. .	. .
	Mean		2.41	2.08	2.05	. .	. .	90,000	37,300	43,300	43,900	. .	. .	69.1	80.3	81.2	. .	. .
C1	16	6″ × 4″ × ⅜″	3.53	3.17	3.15	3.11	3.06	131,000	37,100	41,300	41,600	42,100	42,800	71.9	80.0	80.7	81.6	82.9
	17		3.54	3.18	3.16	3.12	3.07	125,700	35,500	39,500	39,700	40,300	40,900	68.8	76.6	76.9	78.1	79.3
	18		3.50	3.14	3.12	3.07	3.03	128,200	36,600	40,800	41,100	41,800	42,300	70.9	79.1	79.7	81.0	82.0
	Mean		3.52	3.16	3.14	3.10	3.05	128,300	36,400	40,500	40,800	41,400	42,000	70.5	78.6	79.1	80.2	81.4
C2	19	6″ × 4″ × ⅜″	3.50	3.20	3.17	2.90	2.83	131,500	37,600	41,100	41,500	45,300	46,500	72.9	79.7	80.4	87.8	90.1
	20		3.50	3.19	3.17	2.89	2.82	130,200	37,200	40,800	41,100	45,000	46,200	72.1	79.1	79.7	87.2	89.5
	21		3.50	3.19	3.17	2.89	2.82	131,900	37,700	41,300	41,600	45,600	46,800	73.0	80.1	80.7	88.4	90.7
	Mean		3.50	3.19	3.17	2.89	2.82	131,200	37,500	41,100	41,400	45,300	46,500	72.7	79.6	80.3	87.8	90.1
D1	22	2-3″ × 3″ × 5/16″	3.44	2.88	2.84	. .	. .	134,100	39,000	46,600	47,200	. .	. .	64.0	76.4	77.4	. .	. .
	23		3.43	2.87	2.83	. .	. .	136,500	39,800	47,600	48,200	. .	. .	65.2	78.1	79.0	. .	. .
	24		3.50	2.92	2.88	. .	. .	139,100	39,800	47,700	48,300	. .	. .	65.2	78.2	79.2	. .	. .
	Mean		3.46	2.89	2.85	. .	. .	136,600	39,500	47,300	47,900	. .	. .	64.8	77.6	78.5	. .	. .
D2	25	2-3″ × 3″ × 5/16″	3.43	2.87	2.83	2.48	2.41	137,900	40,100	48,000	48,700	55,600	57,200	65.7	78.7	79.8	91.2	93.8
	26		3.43	2.87	2.83	2.47	2.40	140,400	40,900	48,900	49,600	56,800	58,500	67.0	80.2	81.3	93.1	95.9
	27		3.42	2.86	2.82	2.46	2.39	138,800	40,600	48,500	49,200	56,400	58,100	66.6	79.5	80.6	92.5	95.2
	Mean		3.43	2.87	2.83	2.47	2.40	139,000	40,500	48,500	49,200	56,300	57,900	66.4	79.5	80.6	92.3	95.0

TABLE II — *Continued*

	1907 Tests.																	
A3	28	3½″ × 3″ × ⅜″	2.24	1.91	1.89	1.96	1.92	94,400	42,100	49,400	49,900	48,100	49,200	72.9	85.5	86.5	83.2	85.1
	29		2.26	1.93	1.91	1.98	1.94	96,900	42,900	50,200	50,700	48,900	49,900	74.3	86.9	87.8	84.6	86.3
	30		2.25	1.92	1.90	1.98	1.93	98,200	43,600	51,100	51,700	49,600	50,900	75.5	88.5	89.5	85.9	88.0
	Mean		2.25	1.92	1.90	1.97	1.93	96,500	42,900	50,200	50,800	48,900	50,000	74.2	87.0	87.9	84.6	86.5
A4	31	3½″ × 3″ × ⅜″	2.27	1.93	1.91	1.99	1.94	99,600	43,900	51,600	52,100	50,000	51,400	76.0	89.3	90.2	86.5	89.0
	32		2.23	1.91	1.89	1.96	1.91	97,300	43,600	51,000	51,500	49,600	51,000	75.5	88.3	89.1	85.9	88.2
	33		2.25	1.92	1.90	1.97	1.93	99,200	44,100	51,700	52,200	50,400	51,400	76.3	89.5	90.4	87.1	89.0
	Mean		2.25	1.92	1.90	1.97	1.93	98,700	43,900	51,400	51,900	50,000	51,300	75.9	89.0	89.9	86.5	88.7
A5	34	3½″ × 3″ × ⅜″	2.27	1.93	1.91	1.98	1.94	97,600	43,000	50,600	51,100	49,300	50,300	76.1	89.6	90.5	87.3	89.1
	35		2.28	1.95	1.93	2.00	1.96	98,500	43,200	50,500	51,000	49,300	50,300	76.5	89.5	90.3	87.3	89.1
	36		2.26	1.92	1.90	1.98	1.94	97,900	43,300	51,000	51,500	49,500	5 ,500	76.6	90.3	91.2	87.6	89.4
	Mean		2.27	1.93	1.91	1.99	1.95	98,000	43,200	50,700	51,200	49,400	50,400	76.4	89.8	90.7	87.4	89.2
B4	37	4″ × 3″ × ⅜″	2.41	2.08	2.06	2.10	2.06	100,400	41,700	48,300	48,800	47,900	48,800	77.9	90.1	91.0	89.3	91.0
	38		2.40	2.06	2.04	2.08	2.04	98,300	41,000	47,700	48,200	47,200	48,200	76.5	89.0	90.0	88.0	90.0
	39		2.43	2.10	2.08	2.12	2.07	101,400	41,700	48,300	48,800	47,800	49,000	77.9	90.1	91.0	89.2	91.5
	Mean		2.41	2.08	2.06	2.10	2.06	100,000	41,500	48,100	48,600	47,600	48,700	77.4	89.7	90.7	88.8	90.8
B5	40	4″ × 3″ × ⅜″	2.39	2.06	2.04	2.09	2.04	100,500	42,000	48,800	49,300	48,100	49,300	78.4	91.0	92.0	89.8	91.9
	41		2.41	2.08	2.06	2.11	2.06	103,500	42,900	49,800	50,200	49,000	50,200	80.1	92.9	93.7	91.5	93.7
	42		2.48	2.14	2.12	2.16	2.12	104,500	42,100	48,800	49,300	48,300	49,300	78.6	91.0	92.0	90.1	91.9
	Mean		2.43	2.09	2.07	2.12	2.07	102,800	42,300	49,100	49,600	48,500	49,600	79.0	91.6	92.6	90.5	92.5
B6	43	4″ × 3″ × ⅜″	2.39	2.06	2.04	2.03	1.99	100,600	42,000	48,900	49,300	49,500	50,500	70.3	81.8	82.5	82.8	84.4
B7	44		2.44	2.10	2.08	2.03	1.98	103,500	42,400	49,300	49,800	51,000	52,300	79.1	92.0	92.9	95.1	97.6
B8	45		2.40	2.06	2.04	1.95	1.90	101,800	42,400	49,400	49,900	52,200	53,500	70.9	82.6	83.5	87.3	89.5
C3	46	6″ × 4″ × ⅜″	3.60	3.24	3.22	. .	. .	154,600	42,900	47,700	48,000	. .	. .	72.0	80.0	80.5	. .	. .
	47		3.56	3.20	3.18	. .	. .	150,600	42,300	47,000	47,300	. .	. .	71.0	78.8	79.4	. .	. .
	48		3.58	3.22	3.20	. .	. .	153,300	42,800	47,600	47,900	. .	. .	71.8	79.9	80.3	. .	. .
	Mean		3.58	3.22	3.20	. .	. .	152,800	47,700	47,400	47,700	. .	. .	71.6	79.6	80.1	. .	. .
C4	49	6″ × 4″ × ⅜″	3.56	3.21	3.18	3.31	3.26	150,600	42,300	46,900	47,300	45,500	46,200	71.0	78.6	79.4	76.3	77.5
	50		3.54	3.19	3.16	3.29	3.24	144,100	40,700	45,200	45,600	43,800	44,500	68.3	75.9	76.5	73.5	74.6
	51		3.54	3.19	3.17	3.29	3.25	152,200	43,000	47,700	48,000	46,300	46,800	72.1	80.0	80.5	77.6	78.5
	Mean		3.55	3.20	3.17	3.30	3.25	149,000	42,000	46,600	47,000	45,200	45,800	70.5	78.2	78.8	75.8	76.9
C5	52	6″ × 4″ × ⅜″	3.54	3.18	3.16	3.20	3.16	143,500	40,500	45,100	45,400	44,800	45,400	68.0	75.7	76.1	75.1	76.1
	53		3.53	3.18	3.16	3.20	3.15	148,000	41,900	46,500	46,800	46,300	47,000	70.2	78.0	78.5	77.6	78.9
	54		3.51	3.16	3.14	3.18	3.13	146,400	41,800	46,300	46,600	46,000	46,700	70.1	77.7	78.2	77.1	78.5
	Mean		3.53	3.17	3.15	3.19	3.15	146,000	41,400	46,000	46,300	45,700	46,400	69.4	77.1	77.6	76.6	77.8
D3	55	2-3″ × 3″ × 5/16″	3.43	2.88	2.84	. .	. .	140,000	40,800	48,600	49,300	. .	. .	68.1	81.2	82.4	. .	. .
	56		3.39	2.83	2.79	. .	. .	140,700	41,500	49,700	50,400	. .	. .	69.3	82.9	84.2	. .	. .
	57		3.39	2.83	2.79	. .	. .	140,600	41,500	49,600	50,300	. .	. .	69.3	82.9	84.0	. .	. .
	Mean		3.40	2.85	2.81	. .	. .	140,400	41,300	49,300	50,000	. .	. .	68.9	82.3	83.5	. .	. .
D4	58	2-3″ × 3″ × 5/16″	3.38	2.83	2.80	2.87	2.80	135,600	40,100	47,900	48,400	47,200	48,400	68.2	81.5	82.3	80.3	82.3
	59		3.34	2.79	2.76	2.84	2.76	134,800	40,300	48,300	48,800	47,500	48,800	68.5	82.1	83.0	80.8	83.0
	60		3.37	2.82	2.78	2.87	2.78	130,000	38,600	46,100	46,800	45,300	46,800	65.5	78.5	79.5	77.0	79.6
	Mean		3.36	2.81	2.78	2.86	2.78	133,500	39,700	47,400	48,000	46,700	48,000	67.4	80.7	81.6	79.4	81.6

* Figures of five preceding columns compared with results of test bars.

computed under the assumption that the holes are $\frac{15}{16}$ inch in diameter and again that they are 1 inch in diameter. The least zigzag sections have been computed by assuming the angles to be developed about the corners and taking the net areas on a section passing from the edges of the legs to the centres of the inner rivet holes, then diagonally between centres of rivets. In the results published last year the net areas given were not the least zigzag areas, but were those computed on sections which approximated the fractured sections. In the accompanying table last year's tests have been revised, so that the net zigzag areas shown are the least that can be obtained for those tests.

In studying the results of these tests it should be remembered that the ends of the specimens are not held rigidly in the testing machine and that there are a comparatively small number of angles of any one kind. However, the results, so far as they go, should be studied with a view of determining the most efficient connection. The efficiency of a specimen may be based upon its gross area or upon its minimum net area. This latter area may be either that of a right section or that of a zigzag section. On the whole, it seems most reasonable to base the efficiency on the gross area of the angle, so that if we have a series of angles of the same size — gross cross-section and quality, but with different end-connection — that connection is the most efficient which will allow the angle to carry the maximum load.

Basing our study, therefore, on the stress per square inch of gross area of the angles, and considering all of the angles of a given size, the tests seem to show that for the $3\frac{1}{2} \times 3 \times \frac{3}{8}$ inch angles the greatest efficiency, 76.4 per cent., occurs with those angles, with lugs, having the pull passing through the centre of gravity of the angle in plan. Inasmuch as the efficiencies of the specimens A_3, A_4, and A_5 are about the same, and are much greater than those of A_1 and A_2 tested last year, it appears that this gain in efficiency is due largely to the increased stagger of the inner rivets in the two legs of the angles. The importance of this stagger is seen by comparing A_3 and A_2. Of the specimens A_3, A_4, and A_5, the last two, both of which have the centre of pull coinciding with the centre of gravity instead of with the gauge line, show the greatest efficiency.

For the $4 \times 3 \times \frac{3}{8}$ inch angles the greatest efficiency is obtained from B_4 and B_5, which make a much better showing than the angles of the same size tested last year. The advantage of having the large stagger between the inner rivets of the two legs will be noticed by

comparing an efficiency of 77.4 per cent. for B_4 with an average of 73.4 per cent. for B_6, B_7, and B_8. In B_4 the average net right section is less than the average net zigzag section, while for B_6, B_7, and B_8 the reverse is true.

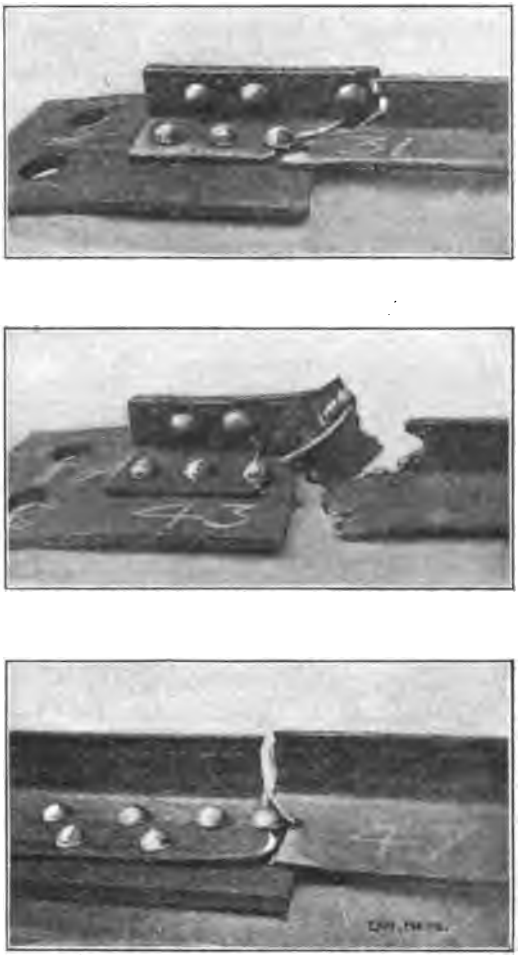

FIG. 3.—THREE TYPICAL FRACTURES
Specimens 31 (A4), 43 (B6), and 47 (C3)

For the 6 × 4 × ⅜ inch angles the greatest efficiency for this year's tests is shown for C_3, which has no lugs, has the first two rivets on the same gauge line, and has the line of pull through the centre of gravity of the specimen. However, a slightly better showing was made

by C_2 of last year's series. C_2 had lugs and had the centre of pull passing through the inner gauge line of the main angle.

Of the specimens composed of two $3 \times 3 \times \frac{5}{16}$ inch angles the greatest efficiency is shown by this year's tests with 68.9 per cent. for D_3, which has no lugs and has the centre of pull passing through the centre of gravity of the angles.

Acknowledgment is due to the American Bridge Company, of New York, for the specimens; to Messrs. C. T. Bartlett and H. B. Orcutt, of the class of 1906, to Mr. A. F. Holmes, Instructor, and to Messrs. F. W. Morrill and H. B. Hastings, of the class of 1907, for the care and thoroughness with which they did the work in the laboratory.

BOOK REVIEWS

Coaling at Sea[1]

The Lidgerwood Company has issued a trade publication of unusual interest, especially in view of the present voyage of the battleship fleet to the Pacific Ocean. It is a description, profusely illustrated, of apparatus for transferring coal from collieries to battleships, or from larger vessels to the smaller torpedo craft.

The pamphlet may be had free upon application to the publisher.

Mining and Geology, Western Australia[2]

The Bulletins of the Geological Survey of Western Australia recently issued continue the description of the geology of that country, with special reference to the mining industry.

Bulletin 23 is the third report on the geological features and mineral resources of the Pilbara gold field, by A. G. Maitland. It takes up in detail six of the individual mining centres, giving a history, an account of the general geology, and a description of the ore deposits of each. These sections are followed by a general summary of the general geology and economic geology of the region.

Bulletin 24 is a detailed account of the Mt. Margaret gold field, by Charles G. Gibson, and like the previous bulletin takes up in detail the general geology, mines, and the statistics of the various portions of this industry.

Bulletin 25 is by R. L. Jack, and deals with the important question of obtaining artesian water in the Kimberley district. This is a pasture

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[1] Lidgerwood-Miller Marine Cableway for Coaling in a Seaway. New York: Lidgerwood Manufacturing Co., 1907.

[2] Geological Survey of Western Australia, Bulletins 23, 24, and 25. Perth, 1906.

area overlying the Carboniferous, Devonian, Silurian, and granite rock. This country is subject to annual droughts of great severity and accompanied by great heat, which are not always relieved by the wet season that is expected to begin in October. An artesian water supply is, therefore, of great importance; and the author of this report finds that in certain portions of the district success may be anticipated in the search for artesian water.

All three of these bulletins are illustrated by numerous maps, plans, and reproductions of photographs.

Beet-Sugar Manufacture[1]

The translation of the second edition of Classen's "Beet-Sugar Manufacture," by Mr. William T. Hall and Mr. George W. Rolfe, follows very closely the text of the German edition, yet the facts are forcibly expressed in a clear and concise manner. The text reads smoothly and is translated in an interesting style.

It is, however, to be regretted that some of the valuable tables in the appendix of the original volume have been omitted in this English translation; they are certainly essential and could have been very easily included.

The author is well known as an authority on beet-sugar manufacture, therefore the translation of this work will be of great assistance to the many sugar chemists who are interested in the details of the work of beet-sugar houses. L. W. P.

Chemical Reagents[2]

This volume is a translation of an extensively revised fourth edition of Krauch's well-known work, which, however, appears under the name of E. Merck as the person immediately responsible. The translator has made some modifications to bring the subject-matter more directly

[1] Beet-Sugar Manufacture. By H. Classen. New York: John Wiley & Sons.

[2] Chemical Reagents: Their Purity and Tests. By E. Merck. Translated by Henry Schenck. New York: Van Nostrand, 1907. 250 + 7 pp. $1.50 net.

into line with American practice. This applies particularly to reagents of gravities not commonly employed abroad. The book is distinctly valuable, and probably represents, in general, as near an approach to a set of standard requirements of purity as it is practicable to lay down. It is a decided advance over the earlier editions of Krauch's work, as there is a closer approximation to quantitative limitations in the tests. It is convenient in form, well printed and indexed, and is a timely addition to chemical literature, since, as the translator points out in the preface, with a suggestion of sarcasm, the report of the Committee of the American Chemical Society covering this field is likely to require a long time for its completion, judging from present progress.

H. P. TALBOT.

STREET RAILWAYS AS INVESTMENTS [1]

THIS book affords the fullest information in regard to the street and interurban railways of the United States, the Insular Possessions, Canada, and Cuba obtainable outside of the regular reports of the various companies. It contains summaries of the annual reports of the companies and a few general tables which show the growth in gross receipts of the entire industry. Among the excellent features of the publication are the maps which it contains, forty-four in number, showing the systems and more important connections of forty-seven separate companies. The general form of this work is the same as in previous years, but each year adds something to its bulk as new roads are built and old roads increase in length of line and volume of business.

In reading the tables one is struck by the steady tendency, year after year, toward larger systems and increased gross earnings. Thus in 1902 there were only thirty-eight companies with gross receipts of $1,000,000 or more, while in 1906 the number in that class was sixty-three. During this same period of five years the total gross receipts of this group increased from $159,336,273 to $275,245,406. The number of companies in this class is significant as indicating a constant tendency toward consolidation. But there has been, also, a large increase in the total number of companies of all sizes and in the total gross

[1] American Street Railway Investments. An Annual Supplement to the Street Railway Journal. Vol. XIV. New York: McGraw Publishing Co., 1907. 54 + 453 pp., 4to.

receipts of the entire industry. There were 437 companies in 1905, with gross receipts of $25,000 or more, and 481 in 1906.

It is noteworthy that the information afforded by the annual reports of the companies is more nearly adequate for the purposes of the investor than in former years. In many cases fairly complete and detailed operating statistics are given, and the matter of plant and equipment is not entirely ignored.

Another important item of information for the investor is the number of people served by a street railway. A mere statement of the population of a place is an imperfect guide at best in this matter, but when "estimates" or "local estimates" are given, as they are in many places in this publication, they should be viewed with a very critical eye. It is well known that such estimates are always unduly optimistic, and the figures given in connection with many street railway reports are even extraordinarily optimistic in character. One is naturally surprised to find that in most cases there has been apparently a greater total increase in population in the five years following 1900 than in the previous decade as given by the census returns. In some cases cities that were going backward before 1900 show a substantial increase in population since that time.

On the whole, however, the work seems to be as complete and reliable as one could expect in view of the immense growth of the industry and the evident inadequacy of the returns made by many of the companies. C. W. D.

A Handbook for the Chemist[1]

This volume of 472 pages, which from its origin might be taken to be merely an advertising catalogue of a large manufacturer, merits more than passing mention and seems to have fairly earned its somewhat ambitious title.

It is actually an encyclopedia of extraordinary compactness and completeness, stating, to quote from its title-page, "names and synonyms; source or origin; chemical nature and formulas, physical form, appearance, and properties; melting and boiling points; solubilities;

[1] Merck's 1907 Index. An Encyclopedia for the Chemist, Pharmacist, and Physician. New York: Merck & Co., 1907.

specific gravities and methods of testing; physiological effects; therapeutic uses; modes of administration; ordinary and maximum doses; incompatibles; antidotes; special cautions; hints on keeping and handling, etc., of the chemicals and drugs used in chemistry, medicine, and the arts," to the extent this information has important bearing on the characteristics and uses of the substance.

Many compounded reagents, such as Fehling Solution and Millon's Reagent, are likewise described. No prices are given, but an ingenious comparative evaluation scale is used.

The book deserves notice as a valuable ready reference work, remarkable for the amount of useful information compacted in such moderate space. GEORGE W. ROLFE.

STANDARD POLYPHASE APPARATUS AND SYSTEMS[1]

THE fifth edition of this well-known book is a new edition in fact as well as in name. Not only are there 100 more pages than in the fourth edition, but the contents have everywhere been subjected to a careful revision which has brought it thoroughly up to date.

The author has largely rewritten and expanded the text, thereby gaining in clearness of expression and in fullness of explanation, the latter point being one in which previous editions left something to be desired.

For some of the old illustrations new ones have been substituted, with considerable advantage to the appearance of the book as well as from the more important standpoint of illustrating the text.

As the author frankly admitted in the preface to the first edition, the treatment of the subject is essentially descriptive rather than analytical in character. The various pieces of apparatus are on the whole regarded as units, and the characteristics of different types are compared from the standpoint of the user rather than from that of the designer. We are not told, for example, how, given certain detailed information as to the construction of a machine, to compute its probable performance, but that with modern commercial machines such and such results can be secured.

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[1] Standard Polyphase Apparatus and Systems. By Maurice A. Oudin. New York: Van Nostrand.

As regards specific changes, the material which was formerly covered in a single chapter with the title, "Station Equipment and General Apparatus," has been rearranged in three chapters under the headings: "Motor Generators, Frequency Changers, and Other Converting Apparatus," "Switchboards and Station Equipment," and "Lightning Protection and Line Construction." In these much new matter has been incorporated, as, for example, the description of the mercury rectifier. A discussion of the new single-phase motors has also been added to the chapters on the induction motor, and the little used monocyclic system has been compressed from a whole chapter into the limits of a single paragraph.

The omission of the report of the Committee on Standardization of the American Institute of Electrical Engineers is doubtless due to the fact that at the time the book went to press the committee was preparing a new report. This has since been issued, and it is to be hoped that it will be added as an appendix in subsequent printings.

It is unfortunate that in bringing out this edition advantage was not taken of the opportunity to substitute the usual notation, which has now been recommended by the Standardization Committee of the American Institute of Electrical Engineers, for the special one employed by the author. In the case of students one of the greatest difficulties arising in the assignment of collateral reading is the confusion resulting from a lack of uniformity in notation, and it seems rather unnecessary, for example, to use the symbols S and U for reactance and impedance instead of the more general x and Z. These being simple cases, it is of less consequence than it would be in a more mathematical treatise, and, in fact, the chief value of the book to students of electrical engineering is as a supplement to more theoretical lecture courses. It is admirably adapted for the use of mechanical engineers and other persons wishing to secure information concerning the general characteristics and uses of polyphase apparatus and systems. C. H. P.

PUBLICATIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

"ON the Art of Cutting Metals," by Frederick W. Taylor, M.E. Sc.D., which was the presidential address presented at the last annual meeting

of the American Society of Mechanical Engineers, has been reprinted and bound by the Society; price, $3.00. This, or any other publication of the Society, may be had by addressing the Secretary, 29 West Thirty-ninth Street, New York. It is not necessary to send orders through members. None of the publications of the American Society of Mechanical Engineers are copyrighted.

PUBLICATIONS[1]

Biology, and Sanitary Research Laboratory and Sewage Experiment Station

C.-E. A. Winslow.—Disposal of Sewage. Paper read at the Ninth Annual School for Instruction of Health Officers, Burlington, Vt., June 19, 1907. *Bulletin, Vermont State Board of Health,* Vol. VIII, pp. 3–12. September, 1907.*

C.-E. A. Winslow.—Public Health and Safety. Review of Legislation, 1906. New York State Library: *Legislation Bulletin,* No. 33, pp. 45–54. August, 1907.*

Chemistry and Chemical Engineering

Arthur A. Blanchard.—Inorganic Preparations. Laboratory Exercises in the Chemistry of the Metallic Elements. Printed for the use of students of Massachusetts Institute of Technology. 80 pp. 1907.

This set of notes was designed to serve as a guide for laboratory work and study in Inorganic Chemistry during the second term of the first year at the Institute of Technology.

It had been felt for some time that qualitative analysis, which had previously been made the basis for laboratory practice during that period, did not fully meet the requirements, and that a course based upon the actual preparation of typical chemical substances might prove more satisfactory, at least for those students whose later work would be largely chemical, and that it would afford ample practice in analysis.

The general purpose of laboratory practice during the first year is to supplement the lectures on inorganic chemistry: first, in giving as broad a conception as possible of chemical processes, their nature, and the simple laws governing them; and, second, to awaken in the student a keen, scientific interest and a spirit of investigation.

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[1] In order that the extent of productive work carried on at the Institute may be better known, it is designed to publish quarterly a list of the publications of officers of the Institute, together with abstracts when possible. In this list the publications are arranged alphabetically by departments and then alphabetically by authors.

The asterisk after the title indicates that a copy of the publication has been placed in the library of the Institute.

Thus the work in the laboratory is to furnish actual experimental experiences in such a way that the student may have something tangible to which to attach his conceptions of chemical facts and principles. To accomplish this, the work must be so planned that it cannot become a mechanical following of instructions, but will be an incentive to study.

The matter of the *technique* of qualitative analysis, or of preparation work, although of very great importance, is quite secondary to the purpose herein outlined.

The plan of the notes for this course is, briefly, as follows:

Nearly all of the preparations selected are of real industrial importance, and for the starting point of each either natural products or crude industrial materials are used, so far as is possible. The course does not aim to be an exhaustive one in chemical preparations; but a limited number of exercises are selected to illustrate the most important types of compounds of the common elements and the most important methods used. The number of exercises furnished is more than any one student will be able to complete in the time allotted; thus all students may not have the same preparations.

The notes for each exercise are divided into three parts:

I. A discussion of the object of the exercise, with an outline of the method and the reasons for the steps involved.

II. Concise working directions, which, if carefully followed, should lead to obtaining a satisfactory product.

III. Questions for study which involve additional laboratory experiments, the consulting of standard text-books kept on the table in the laboratory, and original reasoning.

At the end of each group of exercises is furnished a set of general study questions, which every student is expected to work out irrespective of which of the specific exercises he has performed.

Henry Fay.—Tellurium-Tin Alloys. *Journal American Chemical Society,* Vol. XXIX, pp. 1265–1268.*

Henry Fay.—Determination of Sulphur in Pyrite. *Technology Quarterly,* Vol. XX, No. 1, pp. 27–35. March, 1907.*

Augustus H. Gill.—A Comparison of Apparatus for Testing the Liability of Oils to Produce Spontaneous Combustion. *Journal of the Society of Chemical Industry,* Vol. XXVI, p. 185. March, 1907.*

The two sets of apparatus that have been proposed for this purpose are the Ordway, described by Mrs. Richards,[1] and the Mackey.[2] The former uses fifty grams of oil and an equal quantity of cotton waste heated in an air bath to 105°, the latter fourteen grams oil on half its weight of absorbent cotton heated vertically in a water bath.

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[1] This journal, 4, 346.

[2] Journal of the Society of Chemical Industry, 15, 90.

Besides these, a third apparatus was constructed on the Ordway plan, using a water bath heated under pressure to fifteen pounds and drawing a current of air through it at a definite ratio.

The difficulty with the apparatus first described and made (Ordway's) was that results could not be as easily and accurately duplicated on account of the method of heating. As a result of a series of experiments with different oils, it was found that Mackey's apparatus gave the most concordant and satisfactory results.

Augustus H. Gill.—Engine Room Chemistry. A Compend for the Engineer and the Engineman. New York: Hill Publishing Co., 1907. 187 pp., 47 il., 8vo.*

Augustus H. Gill and *Charles R. Haynes.*—The Probable Efficiency of Accidental Gas Explosions. *Journal American Chemical Society*, Vol. XXIX, pp. 1482–1488. October, 1907.*

Experiments were made with various sized boxes, from 1 to 8 cubic feet capacity and various depths from 1 to 4 feet, with explosive mixtures of air and illuminating gas. The results showed an efficiency of one hundredth of 1 per cent. when the lid was fitted *upon* the box, and of ten times that amount where it fitted *into* the box. This was due to the fact that the lid had to be raised by its own thickness before the box could be vented. These results agree well with those obtained by Dr. Gill and a colleague, each working independently, with some fifty explosions in cavities or boxes from 80 to 7,000 cubic feet capacity.

The efficiency seems to increase if the point of ignition be near the bottom rather than near the top.

Arthur A. Noyes.—The Electrical Conductivity of Aqueous Solutions. Carnegie Institution: *Publication No. 63*, September, 1907. 352 pp., 20 il., 8vo.*

A. G. Woodman and *H. P. Talbot.*—The Fluorine Content of Malt Liquors. *Journal American Chemical Society*, Vol. XXIX, pp. 1362–1366. September, 1907.*

The authors have made determinations of the fluoride content of a number of samples of commercial malt liquors and of brewing materials. About fifty brands, both foreign and domestic, were examined, and samples of brewing sugars, malt, barley, yeast, and waters were tested. The method used was the one described in a previous paper.[1] The results obtained show that the presence of a slight amount of fluoride in malt liquors is the rule rather than the exception, and that this fluoride is derived principally from the malt.

One part of fluorine in 100,000 (10 mgs. per liter) is suggested as the maximum limit of permissible fluoride in malt liquors.

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[1] Journal American Chemical Society, 28, 1437.

Drawing and Descriptive Geometry

Charles L. Adams.—Descriptive Geometry, Part 1. Second edition, enlarged. Boston, October 31, 1907. 161 pp., 255 il., 8vo.

Electrical Engineering

Dugald C. Jackson.—Methods of Electric Lighting for Railway Trains. *Journal of Western Society of Engineers,* Vol. XII, 30 pp. May 15, 1907.*

Dugald C. Jackson.—The Relations of the Engineering Schools to Polytechnic Industrial Education. Presidential Address. *Proceedings of Society for the Promotion of Engineering Education,* Vol. XII, July 2, 1907, and *Science,* N. S., Vol. XXVI, No. 656, July 26, 1907, pp. 104–111.*

Charles H. Porter.—Notation for Polyphase Circuits. *Electric Journal,* Pittsburg, Vol. IV, 9 pp., 7 il. September, 1907.*

George C. Shaad.—Loading Stationary Induction Apparatus. *Electric Journal,* Pittsburg, Vol. IV, pp. 346–351, 5 il. June, 1907.*

English

Allen French.—The Book of Vegetables. New York: Macmillan, April, 1907. 312 pp., 152 il., 12mo.

Geology

H. W. Shimer.—An Almost Complete Specimen of *Strenuella strenua* (Billings). *American Journal of Science,* Vol. XXIII, pp. 199–201. March, 1907. Addendum in April number, p. 319, 2 il.*

Discusses a specimen of this species from Mill Cove, North Weymouth, Mass. The specimen is the most complete yet published and the only one in which an identifiable cephalon is united to the thorax.

H. W. Shimer.—A Lower-Middle Cambrian Transition Fauna from Braintree, Mass. *American Journal of Science,* Vol. XXIV, pp. 176–178, il. August, 1907.*

Discusses the occurrences of five species of fossils characteristic of the middle Cambrian and two of the lower Cambrian from a single large slate bowlder. The bowlder was found in East Braintree, Mass., by Mr. T. A. Watson. This lower-middle Cambrian transition fauna is the first recorded from this region. A description of the individual species is also given.

History and Economics

Davis R. Dewey.—Financial History of the United States. Third edition. Longmans, Green & Co., September, 1907. 350 pp.

Mathematics

H. E. Slaught and *N. J. Lennes.*—High School Algebra. Elementary Course. Boston: Alleyn & Bacon, June, 1907. 12 + 297 pp., il., 12mo.*

Edwin Bidwell Wilson.—Oblique Reflections and Unimodular Strains. *Transactions of the American Mathematical Society,* Vol. VIII, pp. 270–298. April, 1907.*

Is a continuation of the author's earlier investigations on the relation between the projective group (or its subgroups) and the involutory transformations of that group (or its subgroups). The problem of the present paper is to discuss the resolution of unimodular strains in three-dimensional space into the product of oblique linear or planar reflections. The necessary and sufficient conditions are determined for the resolution of a strain into two reflections, and an extended geometric discussion is given for all cases in which such resolution is possible.

Further, it is shown that any unimodular strain may be resolved into the product of three reflections and the method of accomplishing the resolution is indicated. The investigation is carried on by means of vector analysis. This enables the main geometric results to be stated as theorems in the algebra of matrices.

Edwin Bidwell Wilson.—The Revolution of a Dark Particle about a Luminous Centre. *Annals of Mathematics,* Second Series, Vol. VIII, pp. 135–148. April, 1907.*

This paper is a mathematical treatment of some of the questions taken up by Poynting in *Nature,* November 22, 1906. It is shown that the total number of revolutions which such a particle can make about a radiating centre of force obeying the Newtonian law is finite. The approximate solution for the path may be obtained by expanding the Bessel's functions which occur in the solution into the customary trigonometric-power series. In this way the amount of fall toward the centre per revolution, the change in the eccentricity of the approximately elliptic path, and the amount of advance of the apse of that path per revolution may all be obtained. The mathematical investigation, therefore, demonstrates the existence of certain phenomena and determines them quantitatively, whereas without that investigation it is difficult to indicate them even qualitatively.

Mining Engineering and Metallurgy

H. O. Hofman.—Review of C. Schnabel and H. Louis's Handbook of Metallurgy. London and New York: Macmillan. 2 vols., 1905 and 1907. *American Chemical Journal,* 1906, Vol. XXXV, p. 473; 1907, Vol. XXXVIII, p. 379.

H. O. Hofman.—Review of O. Hofmann's Hydrometallurgy of Silver. New York: Hill Publishing Co., 1907. *Journal American Chemical Society,* Vol. XXIX, p. 1246. 1907.

H. O. Hofman.—Recent Improvements in Lead Smelting. *Mineral Industry,* Vol. XV, p. 522. 1907.

Robert H. Richards.—Wilfley Table.[1] *Transactions of the American Institute of Mining Engineers,* July, 1907.*

Robert H. Richards.—Velocity of Galena and Quartz in Falling Water. *American Institute of Mining Engineers,* April, 1907.

Robert H. Richards.—The Advances in Ore Dressing in the Last Decade. *Mineral Industry,* Vol. XV, pp. 807–809. 1907.

Robert H. Richards and *D. T. Day.*—Useful Minerals in the Black Sands of the Pacific Slope. United States Geological Survey, *Mineral Resources of the United States* for 1905, pp. 1175–1258. 1906.

Robert H. Richards and *C. E. Locke.*—Progress in Gold Milling in 1906. *Mineral Industry,* Vol. XV, pp. 391–402. 1907.

Robert H. Richards and *C. E. Locke.*—Progress in Ore Dressing and Coal Washing in 1906. *Mineral Industry,* Vol. XV, pp. 810–865. 1907.

Naval Architecture

Harold A. Everett.—Glimpses into Some German Shipyards. *International Marine Engineering,* Vol. XII, pp. 286 and 306. July and August, 1907.

Commander William Hovgaard, R.D.N.—On the Speed of Battleships. *Transactions of Society of Naval Architects and Marine Engineers,* Vol. XV. New York, 1907. (Read at the International Congress of Naval Architecture held in Bordeaux, France, June 25, 26, 27, 1907.)

This paper contains an analysis of the means and methods by which a speed increase can be realized in battleships. The following are the main features discussed in the paper:

1. Increase in the percentage weight of displacement allotted to machinery.

[1] Reprinted in full above, pp. 453–478.

2. Increase in size, preserving geometrical similarity in form of hull.
3. Increase in the scales of length, beam, and draught.
4. Increase in fineness.
5. Improvements in propulsive machinery.
6. Influence of speed on free-board, height of geer-axis, and beam.
7. Speed and strength of hull.
8. Speed and hold space.

Conclusion.—The only legitimate method of obtaining a considerable increase of speed is by technical improvements which permit greater power to be developed on a given weight of machinery and fuel. In order to derive full benefit from the increased power, changes must, however, be made in the form of hull, involving primarily an increase in length and fineness. These changes should be accompanied by an increase in beam and free-board.

Since such changes will in all cases involve an increase in hull and armor weight, we must, if it is desired to carry a certain battery and a certain corresponding system of protection, also increase the displacement.

An example is worked out on basis of the design of the United States battleship *Connecticut.*

Institute Publications

Massachusetts Institute of Technology. *Bulletin,* Vol. XLII, No. 4. Programme. Boston, June, 1907.*

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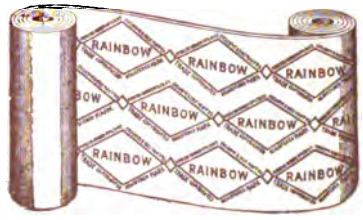

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